<Research Report>

Estimating ARMAX Models for the Hourly Temperature, Wind Speed and Electricity Load for Different Sites in New York and New England

by

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1. Introduction

Electricity load has inherently stochastic characteristics that are determined to a large extent by the ambient temperature, particularly in the summer when air conditioning is a major component of the load. A second source of uncertainty for system operators is the level of generation from renewable sources like wind turbines and solar PV. Conventional generation, such as natural gas turbines, supplies the Net Generation = (Load – Renewable Generation) that is a function of both stochastic components. The uncertainty of Net Generation results in an additional cost to the power system because backup reserves are required to offset this uncertainty and maintain the operating reliability of supply. As the penetration of renewable generation increases, the level of uncertainty of Net Generation also increases, and the amount of reserve capacity committed is determined to a large extent by the accuracy of the forecasts of Net Generation.

In this report, time-series models of hourly load and wind speed are estimated, conditionally on the ambient temperature and seasonal effects, for different sites in New York and New England. In general, the hourly load is much easier to predict than the corresponding wind speed, and the temperature is a more important explanatory variable for load than it is for wind speed. Since the

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spatial correlations across the sites for load and wind speed are also estimated, the models for load and wind speed are multivariate ARMAX models. After some initial analyses, the computation of each ARMAX equation was found to be sufficiently complicated that it was necessary to estimate each equation in two steps. The first step uses OLS to estimate a deterministic mean relationship that is a function of temperature and seasonal effects. The second step uses the computed OLS residuals from the first step to estimate an ARMA structure for the rediduals. Finally, the computed white-noise residuals from the second step are used to compute the variance-covariance matrix across equations.

The purpose of this study is not just limited to estimating models for load and wind speed. The estimated models are also used to compute Monte Carlo simulations for any selected day that provide the input data needed to study the impact of wind generation on the operation of a power system using a stochastic form of Security-Constrained Optimal Power Flow (SCOPF). The simulated profiles of wind speed and load provide realistic forecasting errors and they can be used in the SCOPF to determine the optimum day-ahead commitment of conventional generating capacity for dispatch and reserves from the perspective of a system operator.

This paper is composed by three parts. The first part describes the data specifications and shows how the data for the estimation are acquired, structured and grouped geographically in New York and New England. The second part covers the estimation of ARMAX models for load, wind speed and temperature at different locations in New York and New England. The third part describes the forecasting and simulation procedures for a selected day, and it shows how well the models forecast actual realizations and how quickly the forecasting errors of wind speed and load increase over a 24-hours horizon.

2. Data Specification

Time-series models for the hourly temperature, wind speed, and load were estimated for different locations in New York State and New England using data from 2004 to 2006[1]. The temperature data were obtained from the Northeast Regional Climate Center, the data for wind speed were

[1] In the case of NYC and Long Island load, we analyze only 2006 data because of data availability.

derived using the EWITS data set from the National Renewable Energy Laboratory (NREL), and the load data were taken from the New York Independent System Operator (NYISO) website (<www.nyiso.com>).

Table 2.1: Description of Data Locations in New York and New England

	wind sites	temperature sites[2]	load regions
Area1	1562	North Adams*	NE2
Area2	5549	Beverly Municipal AP*	Boston
Area3	1945	Montpelier	NE1
Area4	3985	Lebanon Municipal	NE1
Area5	196	Berlin Municipal AP*	NE1
Area6	6	Greenville	NE1
Area7	3825	Presque Isle	NE1
Area8	4711	Dunkirk	NY1
Area9	3906	Buffalo*	NY1
Area10	3256	Penn Yan	NY1
Area11	4368	Wheeler	NY1
Area12	4608	Syracuse AP	NY1
Area13	5551	Monticello	NY2
Area14	5511	Albany*	NY2
Area15	4402	Stewart field*	NYC
Area16	6524	Suffolk*	Long Island

Since the overall objective of this research is to study the effects of integrating wind generation into the power grid for New York State and New England (the Northeast Power Coordinating Committee's (NPCC) network), sixteen different sites (seven regions in New England and nine

[2] * Identifies the temperature site used for each load region.

regions in New York) to provide spatially diverse sources of wind generation.[3] Each wind site is associated with a nearby temperature site. In addition, seven load regions are specified, and the details about the locations of the wind sites, temperature sites and load regions are given in Table 2.1. The specifications for the seven load regions follows:

- NE1= Northern New England (Maine, New Hampshire, and Vermont).
- NE2 = Southern New England (Connecticut, Rhode Island, and Massachusetts minus the Boston area).
- Boston = Boston metropolitan area not included in NE2
- NY1 = Western NY State (A, B, C, D, and E from the New York control area load zones map).
- NY2 = Eastern NY State (F, G, H, I, and K from the New York control area load zones map).
- NYC = New York City metropolitan area not included in NY1 or NY2
- Long Island = Long Island area not included in NY1 or NY2

The seven clusters of wind sites in New England are shown in Figure 2.1, and the corresponding nine sites in New York are shown in Figure 2.2. In addition, the load zones in New York are shown in Figure 2.3.

[3] For the analysis of operations on the grid, the simulated wind speeds are converted to the corresponding amounts of potential wind generation from a wind farm at each site.

Figure 2.1: Seven wind sites in New England

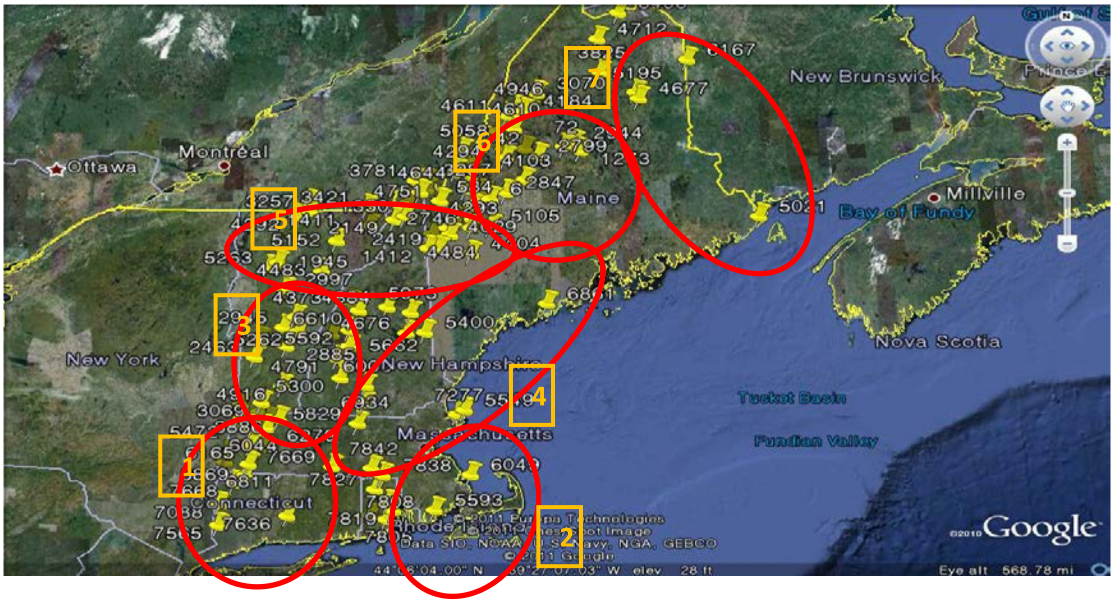


Figure 2.2: Nine wind sites in New York

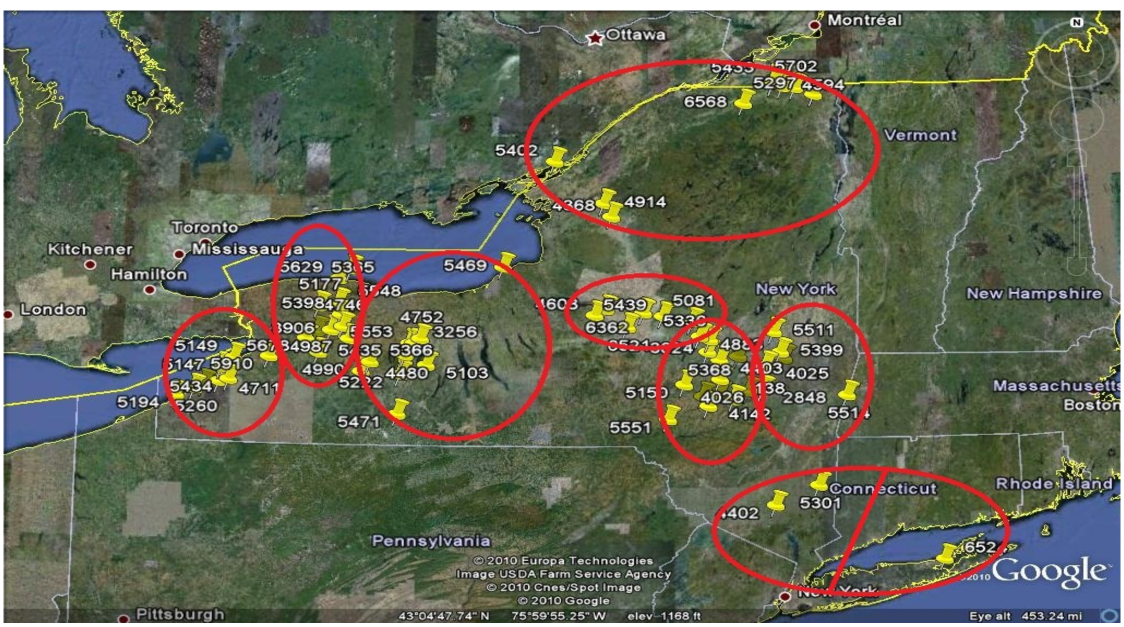
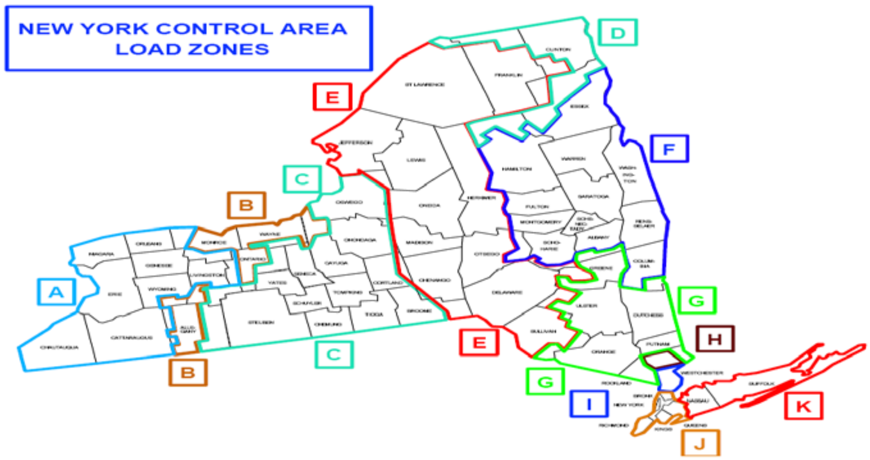


Figure 2.3: New York load zones (source: NYISO web site)



3. Model Estimation

Prior to describing the specific form of individual equations and the estimation results, a summary of the fit of the models for Temperature, Wind Speed, and Load is given in Table 3.1 to Table 3.3. For each equation, the first column is the standard OLS $Adjusted\ R^2$ from the first step of the estimation and the second is a *Pseudo* R^2 derived from the white-noise residuals computed in the second step. For Temperature, for example, the average *Pseudo* R^2 of 99% implies that the one-hour ahead forecasts have a 1% error, and the average $Adjusted\ R^2$ of 78% implies that this forecasting error will increase to 22% for forecasts many hours ahead. In contrast, the model for Log(Wind Speed+1) has an average *Pseudo* R^2 of only 82% and an average $Adjusted\ R^2$ of only 10% because wind speed does not have consistent seasonal and daily patterns and is much harder to forecast accurately. The fit for Log(Load) is much better and similar to Temperature and has an average *Pseudo* R^2 of 99% and an average $Adjusted\ R^2$ of 90%. Load has highly predictable seasonal and daily patterns compared to Wind Speed.

Table 3.1: Measures of goodness-of-fit for the temperature equations

Model	OLS $Adjusted\ R^2$	$Pseudo\ R^2$ (1-B/A)	OLS residual variance (A)	White noise residual variance (B)
NE Site 1 temperature: North Adams	0.7654	0.9918	384.5559	3.145736
NE Site 2 temperature: Beverly Municipal AP	0.7721	0.9920	328.3390	2.6215
NE Site 3 temperature: Monpelier	0.7769	0.9921	435.2015	3.432522
NE Site 4 temperature: Lebanon Municipal	0.7965	0.9909	429.8344	3.907268
NE Site 5 temperature: Berlin Municipal AP	0.7785	0.9900	463.1765	4.634052
NE Site 6 temperature: Greenville	0.8204	0.9953	426.7889	2.003718
NE Site 7 temperature: Presque Isle	0.8040	0.9926	461.6908	3.415714
NY Site 1 temperature: Dunkirk	0.7629	0.9898	354.0255	3.608965
NY Site 2 temperature: Buffalo	0.7844	0.9944	370.3063	2.07303
NY Site 3 temperature: Penn Yan	0.7750	0.9928	357.5103	2.586406
NY Site 4 temperature: Wheeler	0.7691	0.9920	443.1430	3.549677
NY Site 5 temperature: Syracuse AP	0.7772	0.9929	395.8030	2.808287
NY Site 6 temperature: Monticello	0.7949	0.9926	383.1459	2.844962
NY Site 7 temperature: Albany	0.8002	0.9930	393.6827	2.753056
NY Site 8 temperature: Stewart field	0.7917	0.9857	363.2217	5.1778
NY Site 9 temperature: Suffolk	0.7814	0.9851	309.6167	4.60811
Average	**0.7844**	**0.9914**		

Table 3.2: Measures of goodness-of-fit for the wind speed equations

Model	OLS $Adjusted\ R^2$	$Pseudo\ R^2$ (1-B/A)	OLS residual variance (A)	White noise residual variance (B)
Log (Wind speed+1): NE wind site 1562	0.0980	0.8359	0.0390	0.0064
Log (Wind speed+1): NE wind site 5549	0.0698	0.7871	0.0371	0.0079
Log (Wind speed+1): NE wind site 1945	0.1155	0.8355	0.0409	0.0067
Log (Wind speed+1): NE wind site 3985	0.1168	0.8213	0.0364	0.0065
Log (Wind speed+1): NE wind site 196	0.1375	0.8473	0.0394	0.0060
Log (Wind speed+1): NE wind site 6	0.1539	0.8667	0.0455	0.0061
Log (Wind speed+1): NE wind site 3825	0.1022	0.8134	0.0299	0.0056
Log (Wind speed+1): NY wind site 4711	0.1483	0.8312	0.0416	0.0070
Log (Wind speed+1): NY wind site 3906	0.1099	0.8425	0.0397	0.0063
Log (Wind speed+1): NY wind site 3256	0.1258	0.8404	0.0426	0.0068
Log (Wind speed+1): NY wind site 4368	0.0932	0.8315	0.0426	0.0072
Log (Wind speed+1): NY wind site 4068	0.1160	0.8168	0.0415	0.0076
Log (Wind speed+1): NY wind site 5551	0.1138	0.8268	0.0363	0.0063
Log (Wind speed+1): NY wind site 5511	0.0828	0.8062	0.0411	0.0080
Log (Wind speed+1): NY wind site 4402	0.0775	0.7467	0.0353	0.0089
Log (Wind speed+1): NY wind site 6524	0.0902	0.8054	0.0352	0.0069
Average	**0.1095**	**0.8222**		

Table 3.3: Measures of goodness-of-fit for the load equations

Model	OLS $Adjusted\ R^2$	$Pseudo\ R^2$ (1-B/A)	OLS residual variance (A)	White noise residual variance (B)
Log (Load): NE1 load (Western part NY)	0.9079	0.9865	0.0066	0.000089
Log (Load): NE2 load (Eastern part NY)	0.8870	0.9862	0.0082	0.000113
Log (Load): Boston load	0.8930	0.9856	0.0072	0.000104
Log (Load): NY1 load (Northern part NE)	0.8764	0.9883	0.0042	0.000049
Log (Load): NY2 load (Southern part NE)	0.8997	0.9843	0.0080	0.000126
Log (Load): NYC load	0.9046	0.9910	0.0084	0.000076
Log (Load): Long Island load	0.9317	0.9904	0.0112	0.000108
Average	**0.9000**	**0.9875**		

3-1. Temperature Model

Since temperature has strong annual and daily cycles, to capture these effects, several sine and cosine curves were generated. In the final model, temperature is a function of one year, half year, 24-hour, 12-hour cycles, interaction terms between annual and daily cycles. After accounting for these cycles, the residuals still have strong autocorrelations over time. To account for this, an ARMA (Auto-Regressive Moving Average) model is estimated for the residual. The general structure of temperature model is given below:

$\text{Temperature}_t = f_t(\text{Deterministic Cycles}_t) + u_t$

Where, $\left(1 - \sum_{i=1}^{p} \alpha_i L^i\right) u_t = \left(1 + \sum_{i=1}^{q} \theta_i L^i\right) \varepsilon_t$ and L is a lag operator

The standard descriptive statistics for Temperature are given in Table 3.4. With the exception of the high maximum in Area 15, there are no major differences in the values for the different sites.

Table 3.4: Hourly temperature data: basic statistics

variables	Mean	Min	Max	Std Dev
Area 1 temperature (F)	47.70	-15	92	19.61
Area 2 temperature (F)	49.34	-10	96	18.12
Area 3temperature (F)	44.37	-25	91	20.86
Area 4 temperature (F)	45.85	-22	95	20.73
Area 5 temperature (F)	41.76	-33	93	21.52
Area 6 temperature (F)	41.79	-22	91	20.66
Area 7 temperature (F)	41.17	-29	91	21.49
Area 8 temperature (F)	50.27	-13	92	18.82
Area 9 temperature (F)	49.26	-7	95	19.24
Area 10 temperature (F)	49.31	-17	93	18.91
Area 11 temperature (F)	45.78	-24	93	21.05
Area 12 temperature (F)	49.21	-16	95	19.89
Area 13 temperature (F)	47.60	-13	97	19.57
Area 14 temperature (F)	49.43	-15	96	19.84
Area 15 temperature (F)	51.35	-27	122	19.06
Area 16 temperature (F)	51.54	-6	98	17.60

Since SAS was not able to handle the computations for the full model, the estimation was done in two steps. In the first step, the mean relationship with the deterministic cycles was estimated using OLS. In the second step, the OLS residuals from the first step were used to estimate the ARMA structure. Table 3.5 summarizes the results for Temperature in Area 15 for the first step and for an ARMA ((1 2 3 4) (22 23 24 25), 10) in the second step. The estimation results for all areas are summarized in an Appendix. These estimated ARMA models are well behaved and pass the standard white noise test.

Table 3.5: Parameter estimates for Temperature in Area 15

Variables	OLS model for area 15 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	51.35702	957.59	MU	0.02753	0.06
Cy	-21.42043	-282.45	MA1,1(lag1)	1.90468	9.01
Sy	-8.46543	-111.60	MA1,2(lag2)	-1.39176	-3.65
cy1/2	-0.43324	-5.71	MA1,3(lag3)	0.37971	1.62
sy1/2	-0.77936	-10.27	MA1,4(lag4)	-0.06200	-1.70
Ch	-2.78824	-36.76	MA1,5(lag5)	-0.02094	-1.20
Sh	-5.72537	-75.49	MA1,6(lag6)	0.04944	2.86
ch1/2	0.36291	4.78	MA1,7(lag7)	-0.02791	-1.52
sh1/2	1.15111	15.18	MA1,8(lag8)	0.0077347	0.48
Cych	1.12509	10.49	MA1,9(lag9)	-0.01537	-1.00
Cysh	1.32650	12.37	MA1,10(lag10)	0.02676	2.68
Sych	0.39137	3.65	AR1,1(lag1)	2.78401	13.17
Sysh	-0.36220	-3.38	AR1,2(lag2)	-2.93659	-5.18
cy1/2ch1/2	-0.10601	-0.99	AR1,3(lag3)	1.33413	2.46
cy1/2sh1/2	0.53855	5.02	AR1,4(lag4)	-0.18784	-1.02
sy1/2ch1/2	-0.10056	-0.94	AR2,1(lag22)	0.02745	3.95
sy1/2sh1/2	-0.17117	-1.60	AR2,2(lag23)	0.05547	7.88
			AR2,3(lag24)	0.08050	11.43
			AR2,4(lag25)	0.05883	8.46
	Adj R-Sq 0.7917			*Pseudo* R-Sq 0.9857	

To summarize, the general model of the hourly temperature is a function of one year and half year cycles, one day and half day cycles, and cross-effect among yearly and daily cycles.

$$\begin{aligned}\mathrm{Temp}_{\mathrm{it}=} \quad & \beta_{i0} + \beta_{i1}\mathrm{cy}_t + \beta_{i2}\mathrm{sy}_t + \beta_{i3}\mathrm{cy1/2}_t + \beta_{i4}\mathrm{sy1/2}_t + \beta_{i5}\mathrm{ch}_t + \beta_{i6}\mathrm{sh}_t + \beta_{i7}\mathrm{ch1/2}_t \\ & + \beta_{i8}\mathrm{sh1/2}_t + \beta_{i9}\mathrm{cy}_t\mathrm{ch}_t + \beta_{i10}\mathrm{cy}_t\mathrm{sh}_t + \beta_{i11}\mathrm{sy}_t\mathrm{ch}_t + \beta_{i12}\mathrm{sy}_t\mathrm{sh}_t \\ & + \beta_{i13}\mathrm{cy1/2}_t\mathrm{ch1/2}_t + \beta_{i14}\mathrm{cy1/2}_t\mathrm{sh1/2}_t + \beta_{i15}\mathrm{sy1/2}_t\mathrm{ch1/2}_t \\ & + \beta_{i16}\mathrm{sy1/2}_t\mathrm{sh1/2}_t + u_{it}\end{aligned}$$

- $\mathrm{Temp}_{\mathrm{it}}$ = Hourly temperature in Area i for i = 1 to 16

- $cy_t, sy_t, cy1/2_t, sy1/2_t$= yearly pattern variables (cosine and sine curves with year and half-year periods)
- $ch_t, sh_t, ch1/2_t, sh1/2_t$= daily pattern variables (cosine and sine curves with 24-hour and 12-hour periods)

3-2. Wind speed model

For the same reasons explained above for Temperature, the equations for Wind Speed are estimated using a two-step process. The dependent variable is log(Wind Speed+1) because zero values are possible. The explanatory variables are one-year, half-year, 24-hour, 12-hour cycles, CDD (Cooling Degree Days), and HDD (Heating Degree Days) to distinguish the temperature effects in the summer and the winter. The basic structure of wind speed model is given below:

$$\text{Log (Wind speed}_t + 1) = \text{ft (Deterministic Cycles}_t, CDD_t, HDD_t) + u_t$$

$$\text{Where, } \left(1 - \sum_{i=1}^{p} \alpha_i L^i\right) u_t = \left(1 + \sum_{i=1}^{q} \theta_i L^i\right) \varepsilon_t h$$

The standard descriptive statistics are shown in Table 3.6, and there are no striking differences in the values for the different sites.

Table 3.6: Hourly wind speed data: basic statistics

variables	mean	min	Max	std Dev
Area 1 wind speed (m/s)	8.07	0.31	24.05	3.65
Area 2 wind speed (m/s)	6.79	0.19	25.66	3.14
Area 3 wind speed (m/s)	8.28	0.48	25.52	3.90
Area 4 wind speed (m/s)	7.46	0.28	24.84	3.27
Area 5 t wind speed (m/s)	8.95	0.38	27.89	4.08
Area 6 wind speed (m/s)	9.95	0.53	34.91	4.81
Area 7 wind speed (m/s)	7.61	0.25	22.67	3.03
Area 8 wind speed (m/s)	7.03	0.23	21.74	3.44
Area 9 wind speed (m/s)	7.28	0.16	24.57	3.50
Area 10 wind speed (m/s)	7.46	0.18	22.98	3.63
Area 11 wind speed (m/s)	7.20	0.22	27.91	3.55
Area 12 wind speed (m/s)	7.05	0.20	22.92	3.47
Area 13 wind speed (m/s)	8.47	0.39	25.70	3.74
Area 14 wind speed (m/s)	7.61	0.34	26.35	3.63
Area 15 wind speed (m/s)	7.13	0.32	23.60	3.05
Area 16 wind speed (m/s)	6.55	0.12	23.97	2.96

Table 3.6 summarizes the results for log(Wind Speed + 1) in Area 15 for the first step and for an ARMA ((1) (24), 3) in the second step. The estimation results for all areas are summarized in an Appendix. These estimated ARMA models are well behaved and pass the standard white noise test.

Table 3.7: Parameter estimates for log(Wind Speed + 1) in Area 15

Variables	OLS model for area 15 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.89723	334.89	MU	0.0002551	0.06
cy	0.05056	16.08	MA1,1(lag1)	-0.01896	-2.35
sy	0.02137	11.21	MA1,2(lag2)	0.05952	7.65
cy1/2	0.01080	6.46	MA1,3(lag3)	0.0092537	1.28
sy1/2	0.00200	1.20	AR1,1(lag1)	0.85981	166.19
ch	0.04431	27.25	AR2,1 (lag24)	0.06291	10.19
sh	0.04762	27.10			
ch1/2	0.00858	5.45			
sh1/2	-0.00748	-4.73			
CDD	-0.00096577	-3.22			
HDD	-0.00127	-8.97			
	Adj R-Sq 0.0775			*Pseudo* R-Sq 0.7467	

To summarize, the general model for the hourly wind speed is a function of one-year, half-year, 24-hour and 12-hour cycles, CDD, and HDD.

$$\mathrm{Log}(\text{wind speed}_{\mathrm{it}} + 1) = \beta_{\mathrm{i0}} + \beta_{\mathrm{i1}}\mathrm{cy}_t + \beta_{\mathrm{i2}}\mathrm{sy}_{\mathrm{t}} + \beta_{\mathrm{i3}}\mathrm{cy1/2}_{\mathrm{t}} + \beta_{\mathrm{i4}}\mathrm{sy1/2}_{\mathrm{t}} + \beta_{\mathrm{i5}}\mathrm{ch}_{\mathrm{t}}$$

$$+\beta_{\mathrm{i6}}\mathrm{sh}_{\mathrm{t}} + \beta_{\mathrm{i7}}\mathrm{ch1/2}_{\mathrm{t}} + \beta_{\mathrm{i8}}\mathrm{sh1/2}_{\mathrm{t}} + \beta_{\mathrm{i9}}\mathrm{CDD}_{\mathrm{t}} + \beta_{\mathrm{i10}}\mathrm{HDD}_{\mathrm{t}} + u_{it}$$

- $\mathrm{Log}(\text{wind speed}_{\mathrm{it}} + 1)$ in Area i, for i = 1 to 16
- $\mathrm{cy}_{\mathrm{t}}, \mathrm{sy}_{\mathrm{t}}, \mathrm{cy1/2}_{\mathrm{t}}, \mathrm{sy1/2}_{\mathrm{t}}$= yearly pattern variables (cosine and sine curves with year and half-year periods)

- $\mathrm{ch}_t, \mathrm{sh}_t, \mathrm{ch}1/2_t, \mathrm{sh}1/2_t$= daily pattern variables (cosine and sine curves with 24-hour and 12-hour periods)
- $\mathrm{CDD}_t, \mathrm{HDD}_t$ = Cooling Degree Days and Heating Degree Days

3.3 Load Model

The models for Load are estimated using the same two-step procedure as the models for Temperature and Wind Speed. The standard descriptive statistics are shown in Table 3.8, and unlike the values for Temperature and Wind Speed, there are substantial differences in the values for the different regions.

Table 3.8: Hourly load data: basic statistics

variables	mean	min	Max	std Dev
NE1 load (Mwh)	3371.75	2075	5506	609.68
NE2 load (Mwh)	8706.54	5080	16586	1811.99
Boston load(Mwh)	2926.76	1774	5582	571.18
NY1 load (Mwh)	6487.74	4189	10202.90	954.60
NY2 load (Mwh)	3518.56	967.40	6965	734.94
NYC load(Mwh)	6059.76	1323.61	11346.50	1323.61
Long Island load(Mwh)	2532.17	662.18	5747.70	662.18

Even though temperature is the main explanatory factor influencing the electricity load, raw temperature data cannot explain the load changes directly because loads are affected by high and low temperatures differently. To capture this effect, Cooling Degree Days (CDD)[4] and a modified Heating Degree Days (new HDD)[5] are used as regressors in the model. Linear and squared values of CDD and new HDD are also included in the model.

Since the load is lower during weekends, a weekend variable, equal to one during the week days and following a cosine curve with two-day period during weekends, is included. In addition to these explanatory variables, several sine and cosine cycles are used to capture yearly, weekly, and daily patterns of load. First, load has a clear one-year and half-year pattern related to the increased power demand for cooling in the summer and heating in the winter. Next, the weekly pattern of load shows a marked increase during the Monday-Friday workweek and is significantly reduced during the weekend. Lastly, load also has a strong daily pattern. The daily load increases during working hours and decreases at night. The yearly sine and cosine cycles have one-year and half-year periods. For the weekly patterns, three cycles (one-week, half-week, and quarter-week) are added, and the three daily cycles have 24-hour, 12-hour, and 6-hour periods. In addition, the daily patterns of load in the summer and winter are very different from each other. Using this information, a new variable, *winter*, was created that is equal to zero during summer and equal (1 - cosine) during the winter. In addition to *winter*, another variable, *summer*, is equal to zero during the winter and (1 - cosine) during the summer.

To provide additional flexibility for the daily pattern of load, seven Lagrange polynomial weights (w71, w72, w73, w74, w75, w76, w77) are specified to represent a sixth order polynomial for 24 hours. The seven fixed base points are (0, 3, 7, 9, 15, 19, 23) and the corresponding seven regressors are calculated using the formulations below for i = 0, 1, 2, … 23.

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[4] CDD = Max (Temperature - 65, 0)

[5] New HDD = Max (40 - Temperature, 0)

$$w71 = \frac{(i-3)(i-7)(i-11)(i-15)(i-19)(i-23)}{(0-3)(0-7)(0-11)(0-15)(0-19)(0-23)}$$

$$w72 = \frac{(i-0)(i-7)(i-11)(i-15)(i-19)(i-23)}{(3-0)(3-7)(3-11)(3-15)(3-19)(3-23)}$$

$$w73 = \frac{(i-0)(i-3)(i-11)(i-15)(i-19)(i-23)}{(7-0)(7-3)(7-11)(7-15)(7-19)(7-23)}$$

$$w74 = \frac{(i-0)(i-3)(i-7)(i-15)(i-19)(i-23)}{(11-0)(11-3)(11-7)(11-15)(11-19)(11-23)}$$

$$w75 = \frac{(i-0)(i-3)(i-7)(i-11)(i-19)(i-23)}{(15-0)(15-3)(15-7)(15-11)(15-19)(15-23)}$$

$$w76 = \frac{(i-0)(i-3)(i-7)(i-11)(i-15)(i-23)}{(19-0)(19-3)(19-7)(19-11)(19-15)(19-23)}$$

$$w77 = \frac{(i-0)(i-3)(i-7)(i-11)(i-15)(i-19)}{(23-0)(23-3)(23-7)(23-11)(23-15)(23-19)}$$

The first and last regressors, w71 and w77, are dropped from the model to make their coefficients zero. In other words, the polynomial is restricted to start and end at zero. The last step is to multiply the five Lagrange polynomial regressors by the *winter* and *summer* variables. In this way, the changes in the daily pattern of load from fall to winter and back to spring, and from spring to summer and back to fall occur gradually. Since the daily pattern of load is complicated and cannot be represented effectively by these variables alone, interaction terms between annual and daily cycles are also included.

Table 3.9 summarizes the results for log(Load) in Area 15 for the first step and for an ARMA ((1) (24) (48), 6) in the second step. The estimation results for all areas are summarized in an Appendix. These estimated ARMA models are well behaved and pass the standard white noise test.

Table 3.9: Parameter estimates for log(Load) in Area 15

Variables	OLS model for NYC load		Variable	ARIMA model for Residual	
	Parameter	t Value		Parameter	t Value
Intercept	3.72613	1695.49	MU	0.0016161	1.15
t	0.00000353	14.27	MA1,1(lag1)	-0.50340	-24.03
cy	-0.02573	-37.09	MA1,2(lag2)	-0.36238	-14.75
sy	-0.01010	-12.34	MA1,3(lag3)	-0.20585	-8.30
cy1/2	0.02547	25.22	MA1,4(lag4)	-0.13591	-6.21
sy1/2	0.02653	44.05	MA1,5(lag5)	-0.12796	-7.21
cw	-0.02726	-48.32	MA1,6(lag6)	-0.05869	-4.32
sw	-0.00484	-11.24	AR1,1(lag1)	0.73433	40.08
cw1/2	-0.01341	-27.65	AR2,1(lag24)	0.36218	33.87
sw1/2	-0.00535	-12.47	AR3,1(lag48)	0.07812	6.88
cw1/4	0.00387	8.98			
sw1/4	-0.00117	-2.74			
ch1/2	0.00998	8.24			
sh1/2	-0.02511	-24.46			
ch1/4	-0.00193	-4.02			
Sh1/4	-0.00157	-3.51			
ch	-0.02308	-17.62			
sh	-0.05090	-38.05			
wc	0.00579	7.93			
CDD	0.00672	32.15			
newHDD	0.00104	5.59			
CDD^2	-0.00004953	-5.26			
$newHDD^2$	0.00001513	1.80			
cych	-0.00857	-12.72			
sysh	-0.00440	-7.15			
cysh	-0.01622	-22.15			
sych	-0.00384	-6.32			
*winter*w72	0.00176	1.07			
*winter*w73	0.00686	3.96			
*winter*w74	0.02079	12.60			
*winter*w75	0.01816	10.95			
*winter*w76	0.00859	5.16			
*summer*w72	-0.01645	-10.05			
*summer*w73	-0.00133	-0.77			
*summer*w74	0.00737	4.43			
*summer*w75	0.00797	4.65			
*summer*w76	0.00340	2.03			
	Adj R-Sq 0.9046			*Pseudo* R-Sq 0.9910	

To summarize, the log(Load) in the first step is a function of a time trend, annual, weekly, and daily cycles, CDD, new HDD, weekend cycles, and interactions among *winter*, *summer*, and the Lagrange polynomials.

$$
\begin{aligned}
\mathrm{Log}(\mathrm{load}_{\mathrm{it}}) = \ & \beta_{i0} + \beta_{i1}\mathrm{t} + \beta_{i2}\mathrm{cy}_t + \beta_{i3}\mathrm{sy}_\mathrm{t} + \beta_{i4}\mathrm{cy1/2}_\mathrm{t} + \beta_{i5}\mathrm{sy1/2}_\mathrm{t} + +\beta_{i6}\mathrm{cw}_t + \beta_{i7}\mathrm{sw}_\mathrm{t} \\
& + \beta_{i8}\mathrm{cw1/2}_\mathrm{t} + \beta_{i9}\mathrm{sw1/2}_\mathrm{t} + \beta_{i10}\mathrm{cw1/4}_\mathrm{t} + \beta_{i11}\mathrm{sw1/4}_\mathrm{t} \quad + \beta_{i12}\mathrm{ch1/2}_\mathrm{t} \\
& + \beta_{i13}\mathrm{sh1/2}_\mathrm{t} + \beta_{i14}\mathrm{ch1/4}_\mathrm{t} + \beta_{i15}\mathrm{sh1/4}_\mathrm{t} + \beta_{i16}\mathrm{ch}_\mathrm{t} + \beta_{i17}\mathrm{sh}_\mathrm{t} + \beta_{i18}\mathrm{wc}_\mathrm{t} \\
& + \beta_{i19}\mathrm{CDD}_\mathrm{t} + \beta_{i20}\mathrm{newHDD}_\mathrm{t} + \beta_{i21}{CDD^2}_\mathrm{t} + \beta_{i22}{newHDD^2}_\mathrm{t} + \beta_{i23}\mathrm{cy}_\mathrm{t}\mathrm{ch}_\mathrm{t} \\
& + \beta_{i24}\mathrm{sy}_\mathrm{t}\mathrm{sh}_\mathrm{t} + \beta_{i25}\mathrm{cy}_\mathrm{t}\mathrm{sh}_\mathrm{t} + \beta_{i26}\mathrm{sy}_\mathrm{t}\mathrm{ch}_\mathrm{t} \\
& + \beta_{i27}winter_\mathrm{t}\mathrm{w72}_\mathrm{t} + \beta_{i28}winter_\mathrm{t}\mathrm{w73}_\mathrm{t} + \beta_{i29}winter_\mathrm{t}\mathrm{w74}_\mathrm{t} + \beta_{i30}winter_\mathrm{t}\mathrm{w75}_\mathrm{t} \\
& + \beta_{i31}winter_\mathrm{t}\mathrm{w76}_\mathrm{t} + \beta_{i32}summer_\mathrm{t}\mathrm{w72}_\mathrm{t} + \beta_{i33}summer_\mathrm{t}\mathrm{w73}_\mathrm{t} \\
& + \beta_{i34}summer_\mathrm{t}\mathrm{w74}_\mathrm{t} + \beta_{i35}summer_\mathrm{t}\mathrm{w75}_\mathrm{t} + \beta_{i36}summer_\mathrm{t}\mathrm{w76}_\mathrm{t} + u_{it}
\end{aligned}
$$

- $\mathrm{Log}(\mathrm{load}_{\mathrm{it}})$ = Log of load (i=load zone 1 to 7)
- t= time trend
- $\mathrm{cy}_\mathrm{t}, \mathrm{sy}_\mathrm{t}, \mathrm{cy1/2}_\mathrm{t}, \mathrm{sy1/2}_\mathrm{t}$= yearly pattern variables (cosine and sine curve with year and half year period)
- $\mathrm{cw}_\mathrm{t}, \mathrm{sw}_\mathrm{t}, \mathrm{cw1/2}_\mathrm{t}, \mathrm{sw1/2}_\mathrm{t}\ \mathrm{cw1/4}_\mathrm{t}, \mathrm{sw1/4}_\mathrm{t}$= weekly pattern variables (cosine and sine curve with a week, half week, and quarter week period)
- $\mathrm{ch}_\mathrm{t}, \mathrm{sh}_\mathrm{t}, \mathrm{ch1/2}_\mathrm{t}, \mathrm{sh1/2}_\mathrm{t}, \mathrm{ch1/4}_\mathrm{t}, \mathrm{sh1/4}_\mathrm{t}$= daily pattern variables (cosine and sine curve with 24 hours, 12 hours ,and 6 hours period)
- wc_t= weekend cycle which is equal to one during the week days and follows a cosine curve with 2 day period during weekends.
- $\mathrm{CDD}_\mathrm{t}, \mathrm{new\ HDD}_\mathrm{t}$ = Cooling Degree Days and new Heating Degree Days
- *Winter* = winter is equal to zero during summer, followed by (1 - cosine) during the winter
- *Summer= summer is* equal to zero during the winter, followed by (1 - cosine) during the summer

4. Forecasting and Monte Carlo Simulations

Using the estimated models described in Section 3, load and wind speed profiles are simulated for 24 hours on 08/02/2006 using Monte Carlo procedures. The first step is to compute the deterministic part (i.e. the mean) of wind speed and load conditionally on the one-day ahead temperature forecasts on 08/02/2006. The temperature forecasts for the 16 different areas are summarized in Figure 4.1 to 4.16.

Figure 4.1: Actual area 1 temperature and one-day ahead forecast

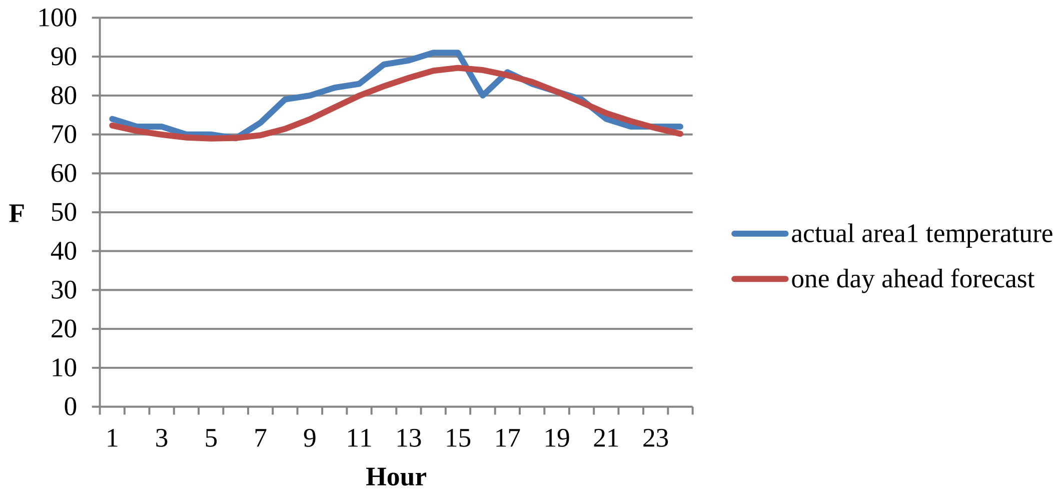


Figure 4.2: Actual area 2 temperature and one day-ahead forecast

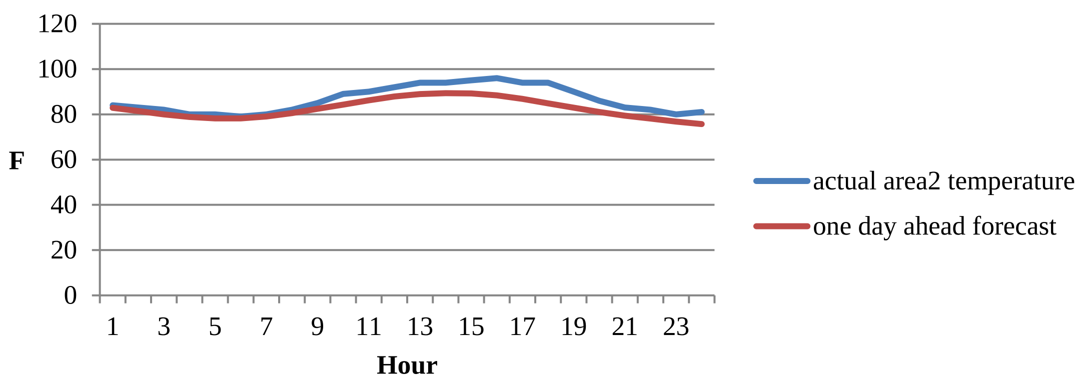


Figure 4.3: Actual area 3 temperature and one-day ahead forecast

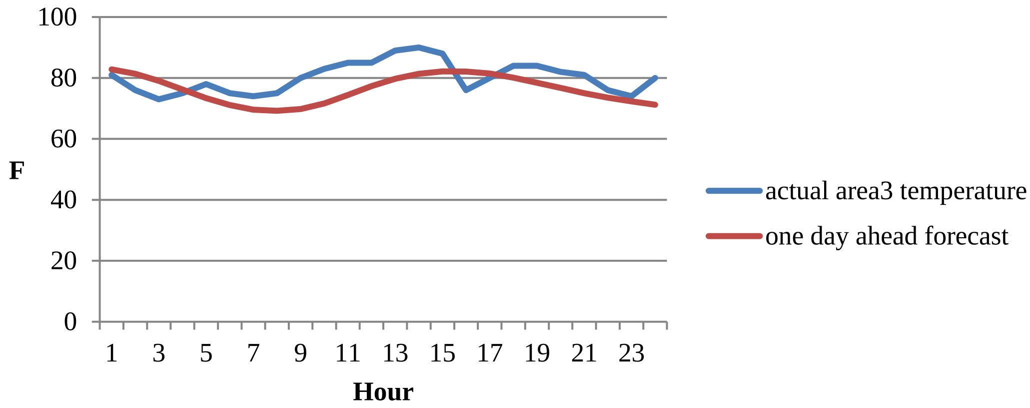


Figure 4.4: Actual area 4 temperature and one-day ahead forecast

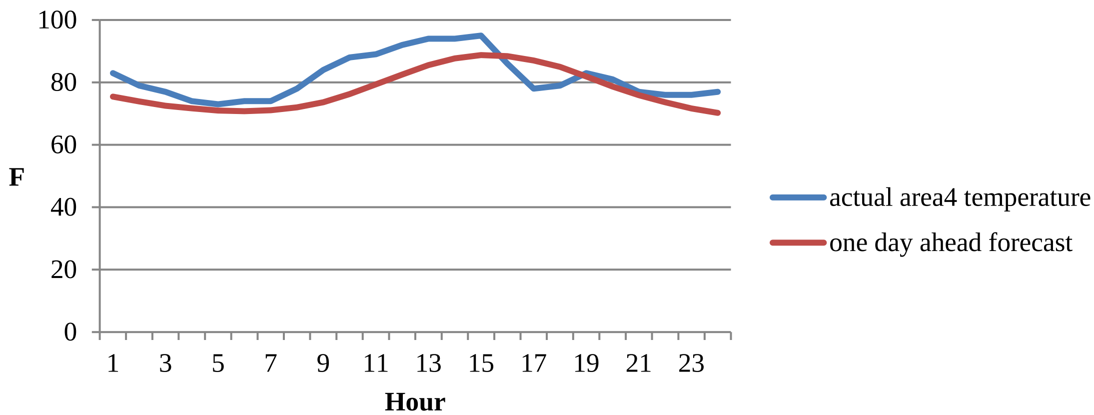


Figure 4.5: Actual area 5 temperature and one-day ahead forecast

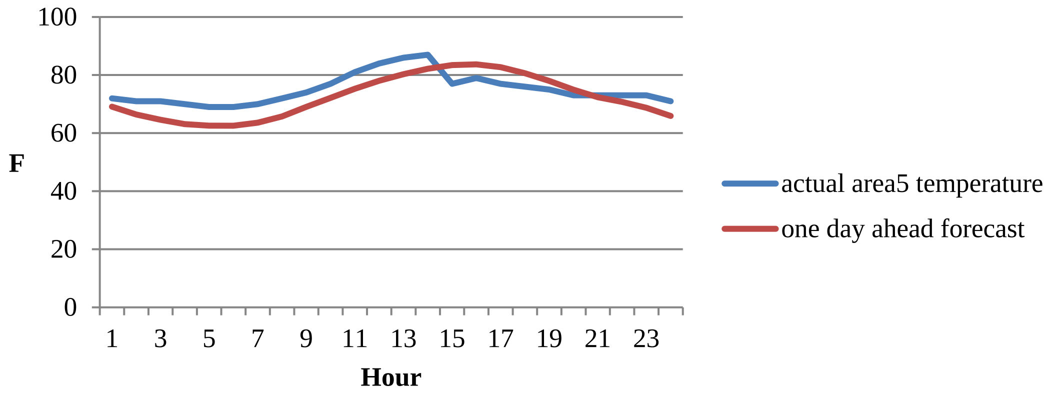


Figure 4.6: Actual area 6 temperature and one-day ahead forecast

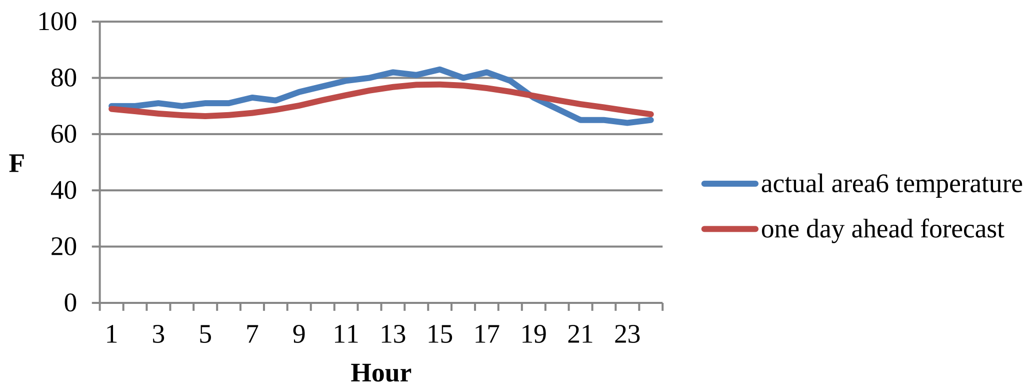


Figure 4.7: Actual area 7 temperature and one-day ahead forecast

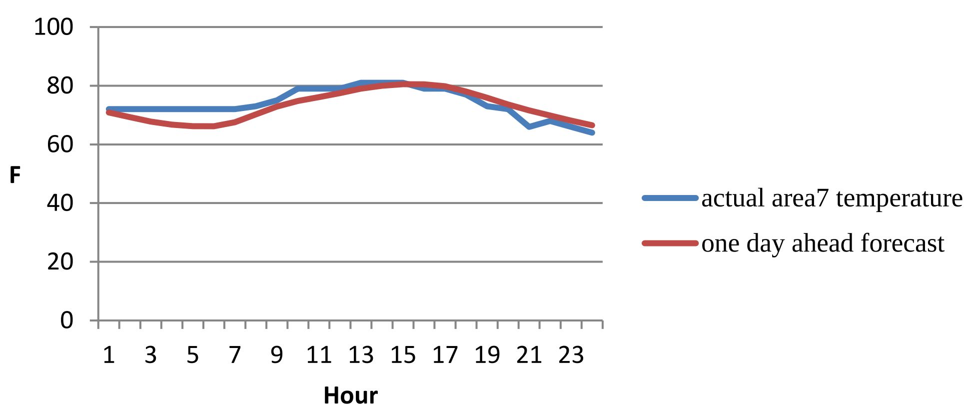


Figure 4.8: Actual area 8 temperature and one-day ahead forecast

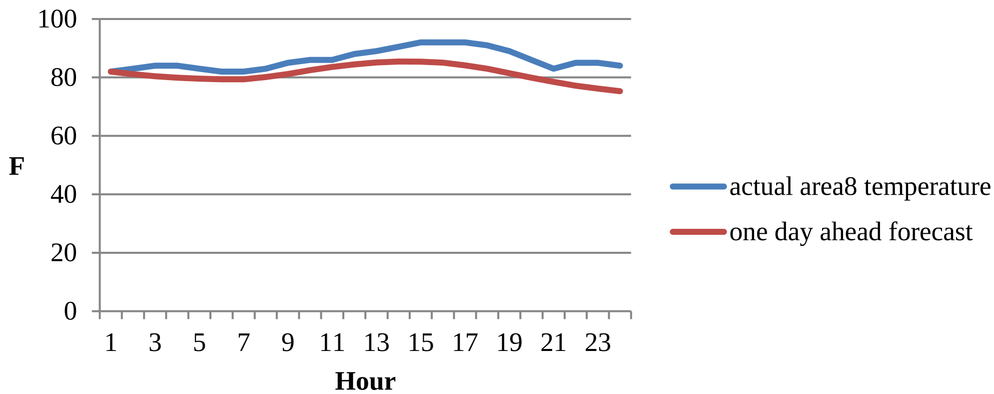


Figure 4.9: Actual area 9 temperature and one-day ahead forecast

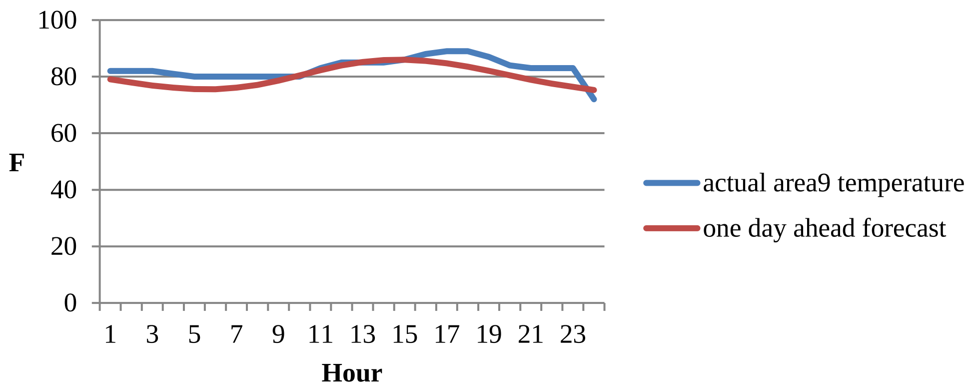


Figure 4.10: Actual area 10 temperature and one-day ahead forecast

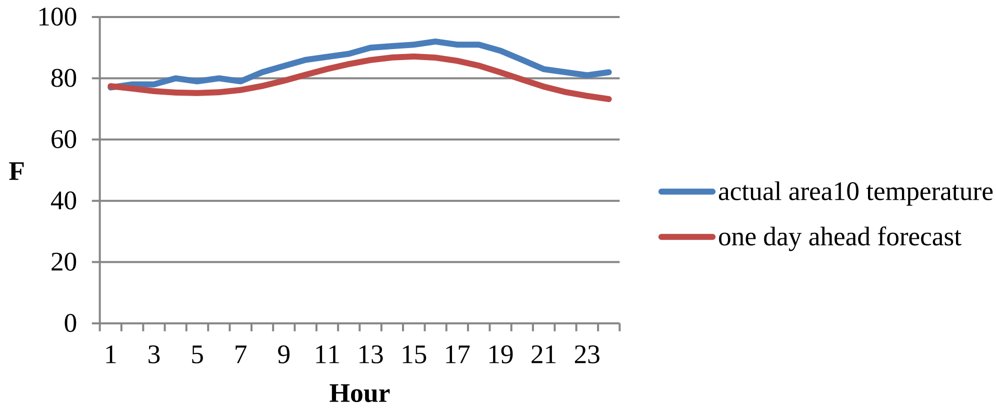


Figure 4.11: Actual area 11 temperature and one-day ahead forecast

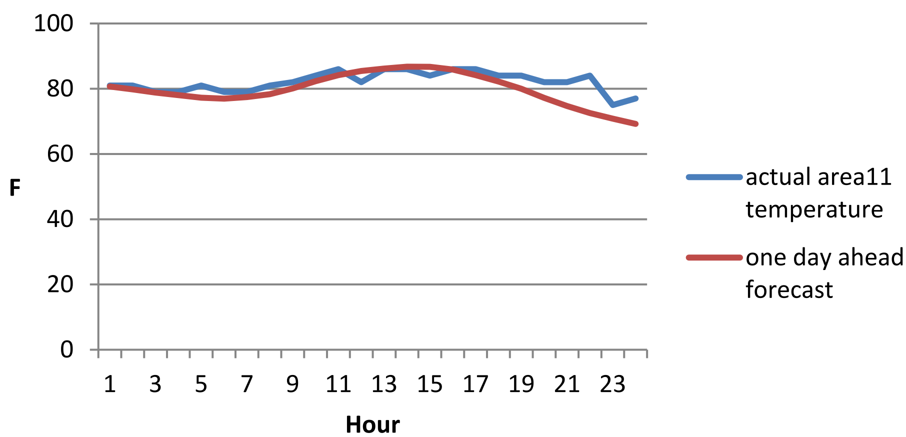


Figure 4.12: Actual area 12 temperature and one-day ahead forecast

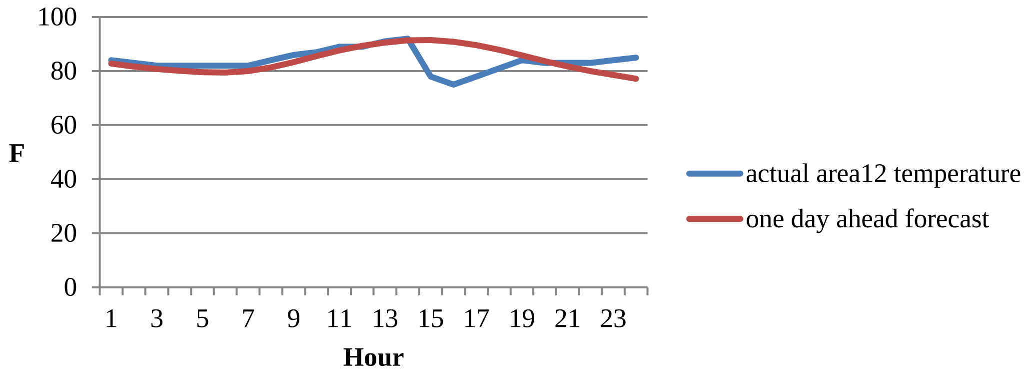


Figure 4.13: Actual area 13 temperature and one-day ahead forecast

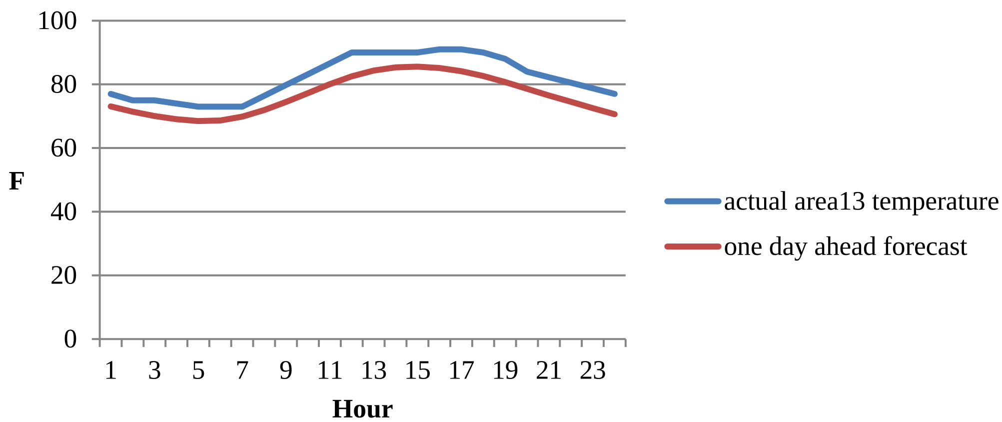


Figure 4.14: Actual area 14 temperature and one-day ahead forecast

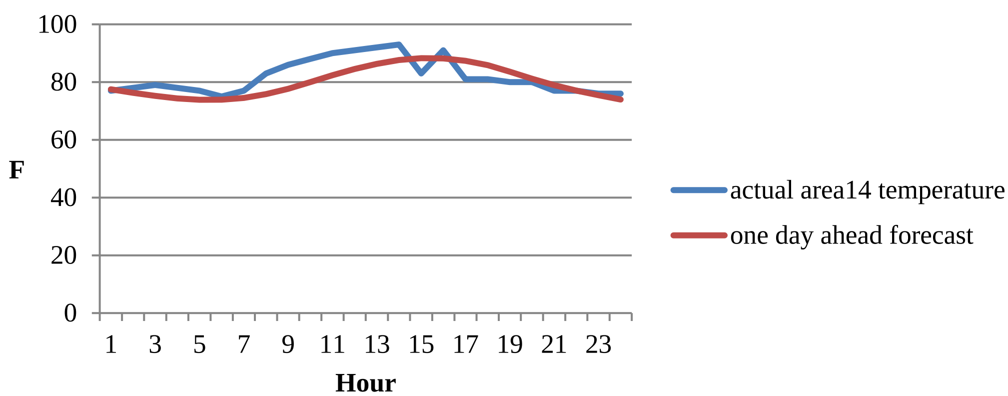


Figure 4.15: Actual area 15 temperature and one-day ahead forecast

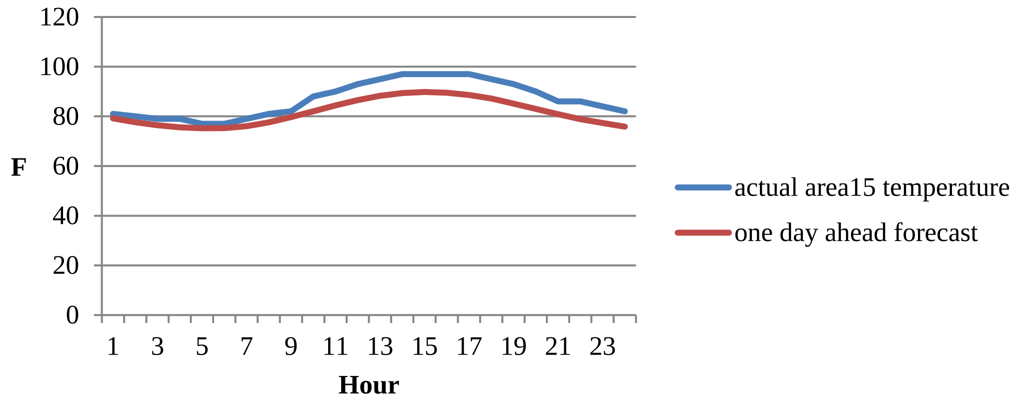
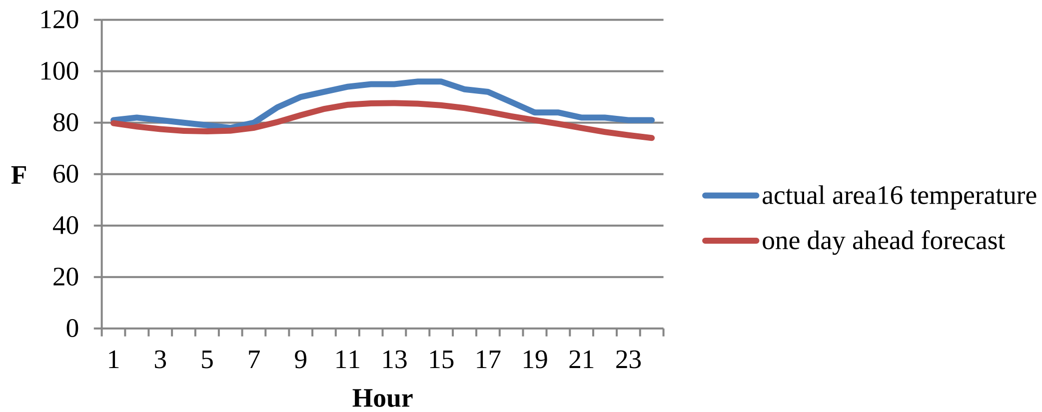


Figure 4.16: Actual area 16 temperature and one-day ahead forecast



For each wind site and load region, the appropriate forecast of temperature is used together with the seasonal cycles to compute the forecasted 24 mean values for 08/02/2006. This completes the first step in the simulation. The second step is to simulate different 24-hour sequences of residuals using the estimated ARMA models in Section 3. For each simulated sequence of residuals, the simulated 24-hour white-noise residuals from the 16 wind sites and 7 load areas are based on a random sequence of 24 random selections from a (16 + 7) multivariate normal density. The estimated ARMA models use these simulated white-noise residuals and the computed OLS and white-noise residuals for the lagged hours prior to 08/02/2006 to forecast the new “raw” residuals (corresponding to the OLS residuals from the estimated mean relationships). This process is repeated 1000 times to give 1000 24-hour sequences of raw residuals.

The final step in the simulation of wind speed is to combine each sequence of residuals with the forecasted hourly mean from step 1 as follows:

$$\text{Wind speed} + 1 = \mathrm{e}^{(\text{forecasted mean from step 1})} * e^{(\text{simulated residual from step 2})}$$

$$\text{Load} = \mathrm{e}^{(\text{forecasted mean from step 1})} * e^{(\text{simulated residual from step 2 })}$$

Figure 4.17 to 4.39 summarize the simulation results for wind speed and load by presenting a random selection of 20 of the 1000 simulated hourly profiles.

Figure 4.17: Simulated wind speed in area 1

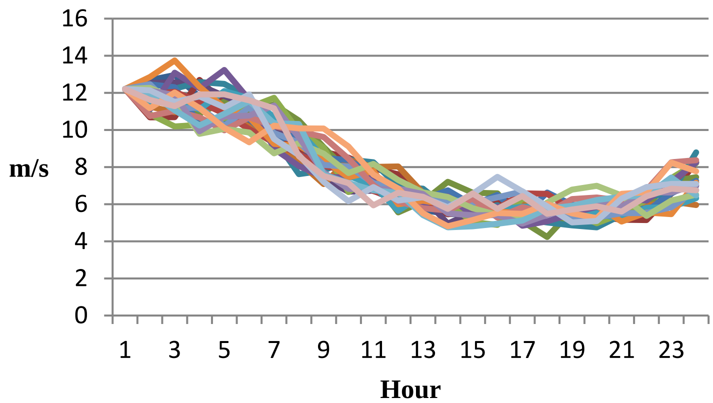


Figure 4.18: Simulated wind speed in area 2

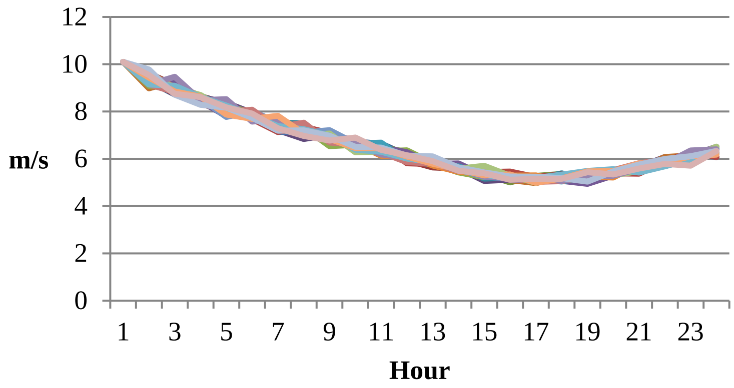


Figure 4.19: Simulated wind speed in area 3

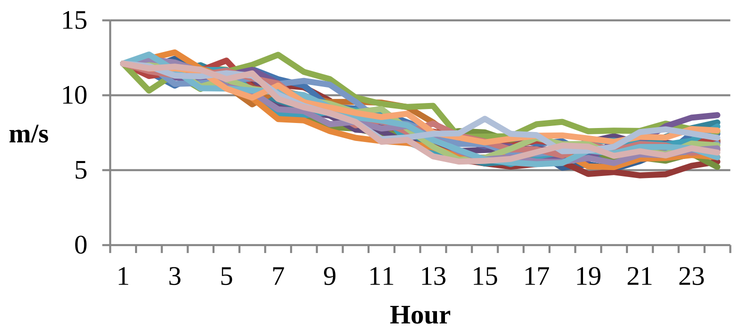


Figure 4.20: Simulated wind speed in area 4

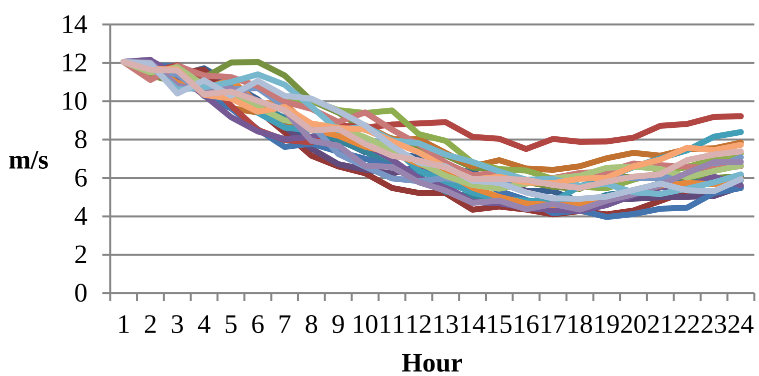


Figure 4.21: Simulated wind speed in area 5

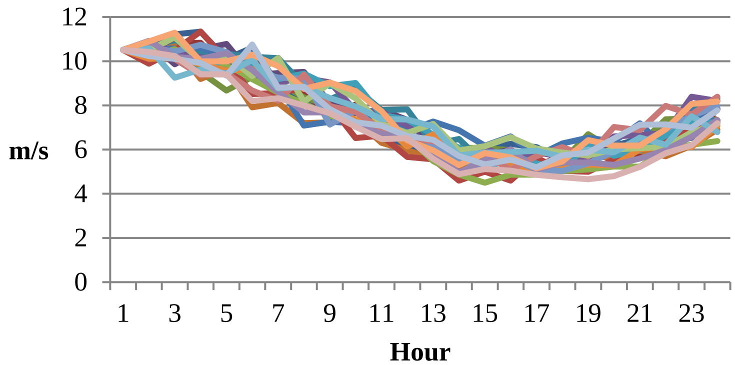


Figure 4.22: Simulated wind speed in area 6

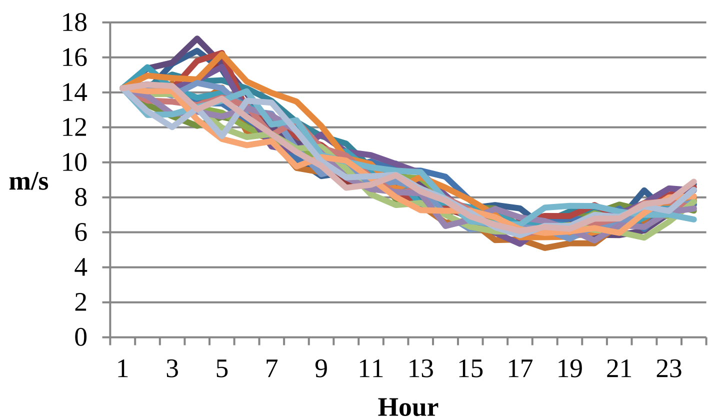


Figure 4.23: Simulated wind speed in area 7

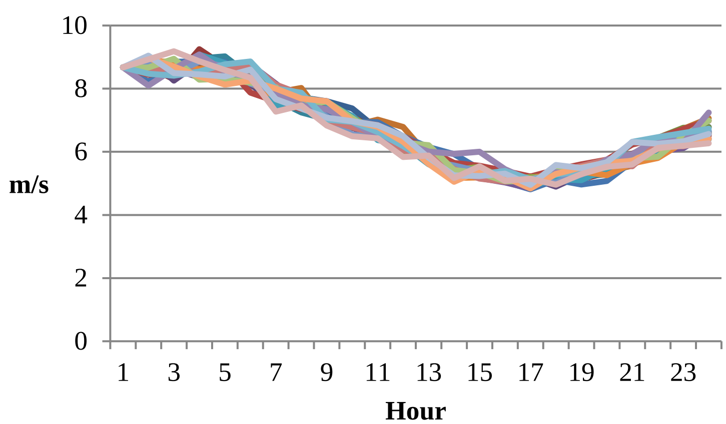


Figure 4.24: Simulated wind speed in area 8

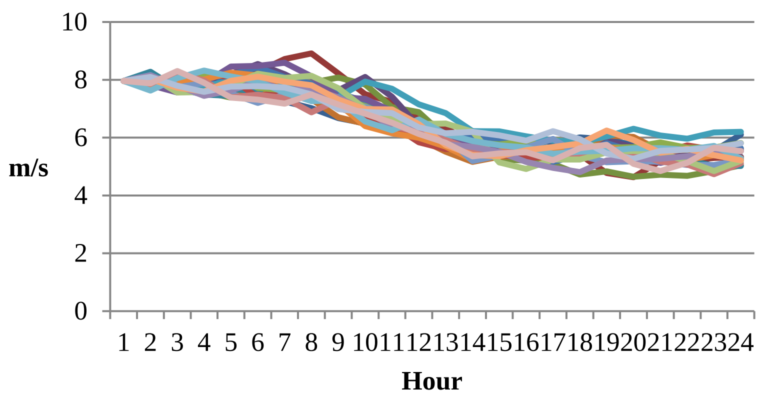


Figure 4.25: Simulated wind speed in area 9

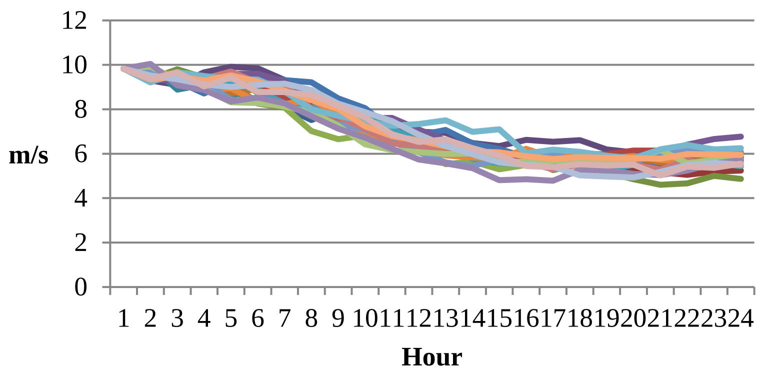


Figure 4.26: Simulated wind speed in area 10

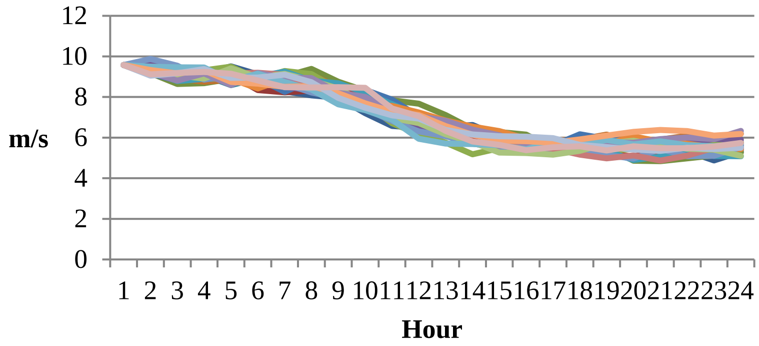


Figure 4.27: Simulated wind speed in area 11

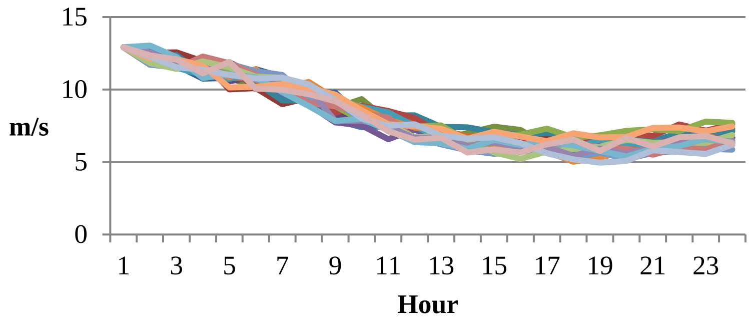


Figure 4.28: Simulated wind speed in area 12

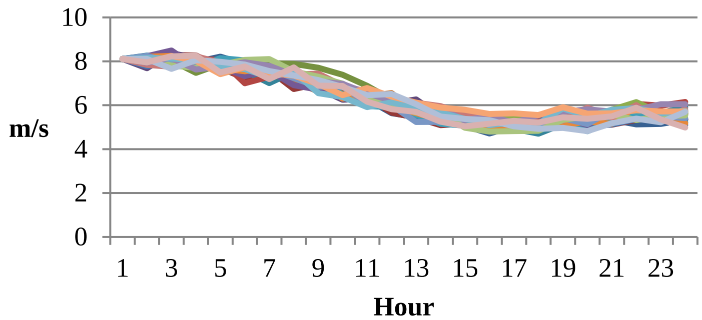


Figure 4.29: Simulated wind speed in area 13

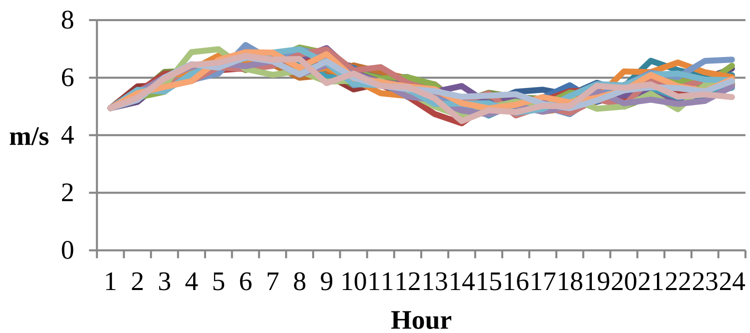


Figure 4.30: Simulated wind speed in area 14

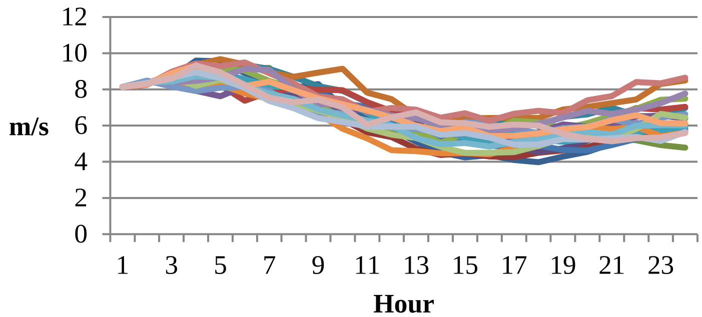


Figure 4.31: Simulated wind speed in area 15

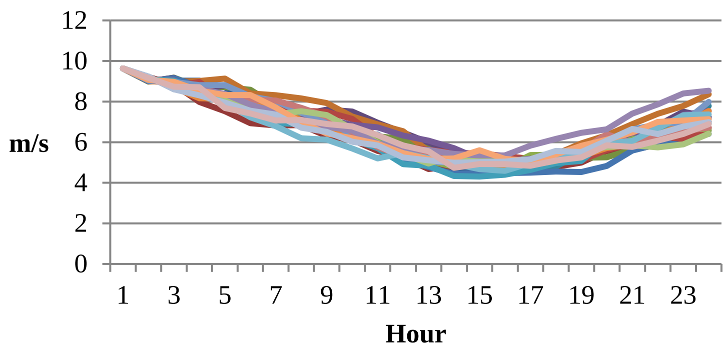


Figure 4.32: Simulated wind speed in area 16

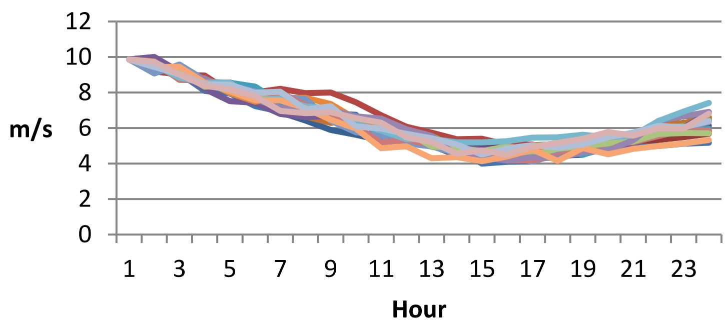


Figure 4.33: Simulated load in NE1

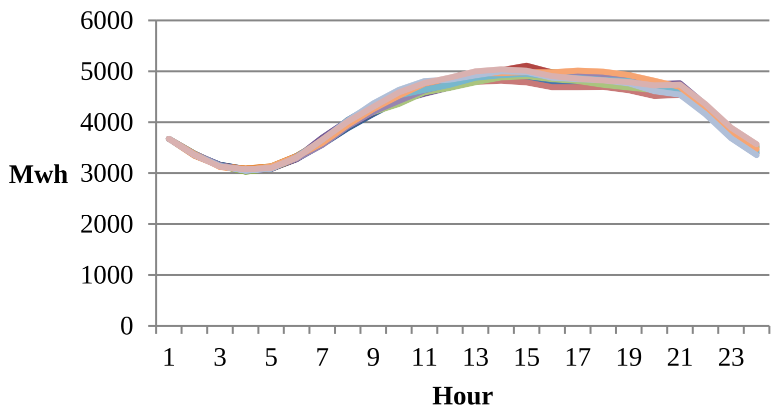


Figure 4.34: Simulated load in NE2

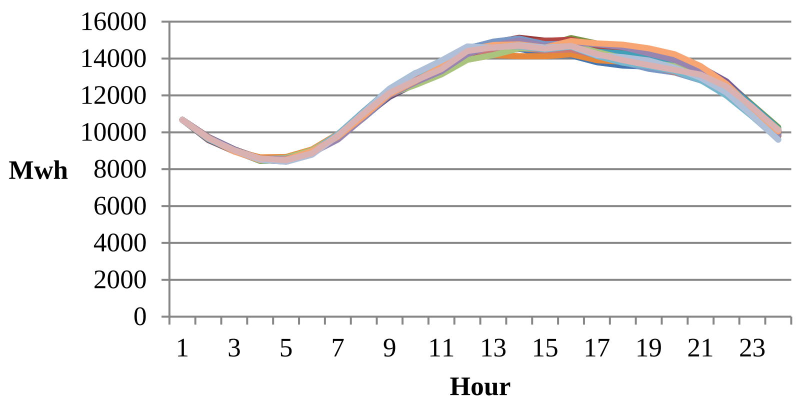


Figure 4.35: Simulated load in Boston

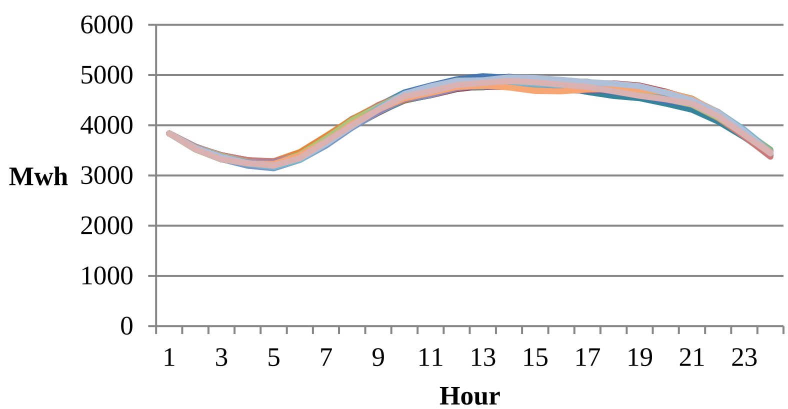


Figure 4.36: Simulated load in NY1

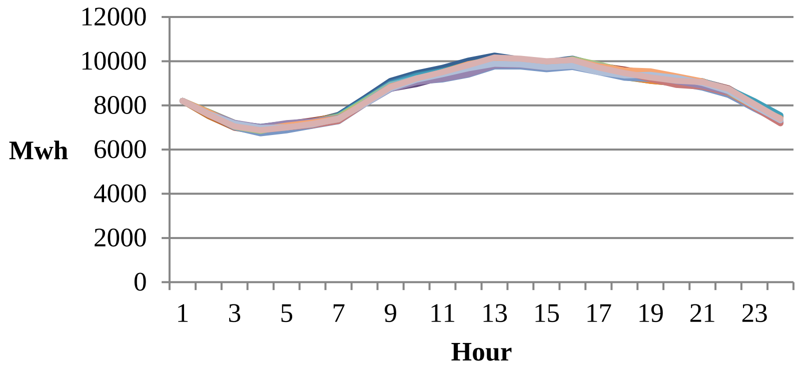


Figure 4.37: Simulated load in NY2

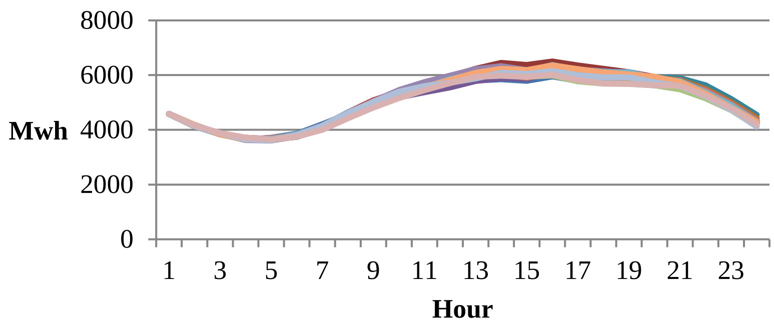


Figure 4.38: Simulated load in NYC

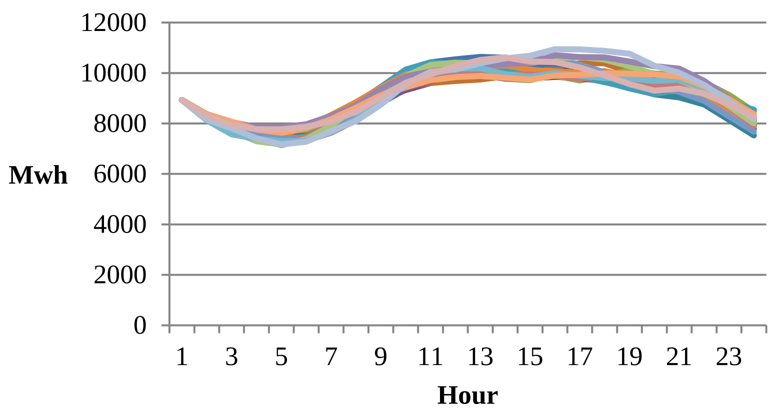
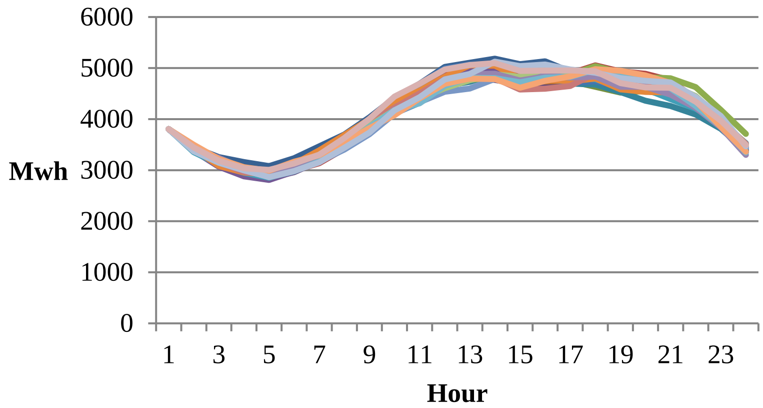


Figure 4.39: Simulated load in Long Island



APPENDIX

Table A.1 to A.15: Estimated OLS and ARMA Models for Temperature

Table A.1: Parameter estimates for Area 1 temperature OLS model and ARIMA model

Variables	OLS model for area 1 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	47.70506	814.54	MU	1.06954	2.20
cy	-21.49949	-259.60	MA1,1(lag1)	0.39762	16.11
sy	-8.50357	-102.66	MA1,2(lag2)	0.76734	33.97
cy1/2	-0.03014	-0.36	MA1,3(lag3)	-0.59780	-25.28
sy1/2	-1.41296	-17.06	MA1,4(lag4)	-0.08792	-7.96
ch	-3.76633	-45.47	MA1,5(lag5)	-0.06374	-6.32
sh	-5.67967	-68.57	MA1,6(lag6)	-0.04542	-4.78
ch1/2	0.50898	6.15	MA1,7(lag7)	-0.02725	-2.95
sh1/2	1.36034	16.42	MA1,8(lag8)	-0.0093657	-1.10
cych	1.87479	16.01	MA1,9(lag9)	0.0094151	1.25
cysh	1.70803	14.58	MA1,10(lag10)	0.03392	4.33
sych	0.47279	4.04	AR1,1(lag1)	1.62849	67.89
sysh	-0.51023	-4.36	AR1,2(lag2)	0.10667	3.03
cy1/2ch1/2	0.00113	0.01	AR1,3(lag3)	-1.55395	-39.03
cy1/2sh1/2	0.39950	3.41	AR1,4(lag4)	0.79479	32.22
sy1/2ch1/2	-0.17801	-1.52	AR2,1(lag10)	0.01763	2.21
sy1/2sh1/2	-0.31678	-2.70	AR2,2(lag20)	0.0094477	1.43
			AR2,3(lag22)	0.04463	6.73
			AR2,4(lag23)	0.07814	11.98
			AR2,5(lag24)	0.14348	21.88
			AR2,6(lag25)	0.07307	11.19
			AR2,7(lag48)	0.07074	11.26
	Adj R-Sq 0.7654			*Pseudo* R-Sq	

Table A.2: Parameter estimates for Area 2 temperature OLS model and ARIMA model

Variables	OLS model for area 2 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	49.34832	925.21	MU	0.81680	1.99
cy	-19.59134	-259.75	MA1,1(lag1)	0.97161	0.11
sy	-9.44748	-125.24	MA1,2(lag2)	0.32858	0.02
cy1/2	-0.06919	-0.92	MA1,3(lag3)	-0.40608	-0.08
sy1/2	-0.08206	-1.09	MA1,4(lag4)	-0.04637	-0.15
ch	-3.48009	-46.14	MA1,5(lag5)	-0.02233	-0.10
sh	-4.31977	-57.27	MA1,6(lag6)	-0.02998	-0.48
ch1/2	0.91025	12.07	MA1,7(lag7)	-0.0006997	-0.00
sh1/2	0.88407	11.72	MA1,8(lag8)	-0.0061207	-0.05
cych	1.54530	14.49	MA1,9(lag9)	-0.01974	-0.15
cysh	0.33513	3.14	MA1,10(lag10)	0.01320	0.14
sych	0.43929	4.12	MA1,11(lag11)	0.0020408	0.01
sysh	-0.10080	-0.94	MA1,12(lag12)	0.02075	0.24
cy1/2ch1/2	-0.20859	-1.96	MA1,13(lag13)	-0.01786	-0.07
cy1/2sh1/2	0.58414	5.48	MA1,14(lag14)	-0.01994	-0.07
sy1/2ch1/2	-0.16643	-1.56	AR1,1(lag1)	2.14812	0.24
sy1/2sh1/2	-0.17835	-1.67	AR1,2(lag2)	-0.94471	-0.04
			AR1,3(lag3)	-0.71861	-0.03
			AR1,4(lag4)	0.50793	0.07
			AR2,1(lag21)	-0.02787	-3.87
			AR2,2(lag22)	-0.0021381	-0.30
			AR2,3(lag23)	0.05447	7.52
			AR2,4(lag24)	0.10138	14.13
			AR2,5(lag25)	0.05391	7.64
			AR2,6(lag48)	0.06389	10.13
	Adj R-Sq 0.7721			*Pseudo* R-Sq	

Table A.3: Parameter estimates for Area 3 temperature OLS model and ARIMA model

Variables	OLS model for area 3 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	44.37150	730.35	MU	0.80727	1.74
cy	-23.28571	-271.05	MA1,1(lag1)	1.90205	16.33
sy	-9.29289	-108.15	MA1,2(lag2)	-1.31642	-7.18
cy1/2	-0.46446	-5.41	MA1,3(lag3)	0.31143	3.67
sy1/2	-1.59882	-18.61	MA1,4(lag4)	-0.04492	-2.85
ch	-3.23495	-37.65	MA1,5(lag5)	0.04579	2.78
sh	-5.36262	-62.42	MA1,6(lag6)	-0.05586	-3.48
ch1/2	0.53218	6.19	MA1,7(lag7)	0.0015704	0.09
sh1/2	1.27857	14.88	MA1,8(lag8)	0.01298	0.82
cych	2.05081	16.88	MA1,9(lag9)	0.0007292	0.05
cysh	1.62595	13.38	MA1,10(lag10)	-0.01351	-0.86
sych	0.39263	3.23	MA1,11(lag11)	0.01099	0.70
sysh	-0.37157	-3.06	MA1,12(lag12)	-0.02376	-1.52
cy1/2ch1/2	-0.23098	-1.90	MA1,13(lag13)	0.04367	3.04
cy1/2sh1/2	0.46176	3.80	MA1,14(lag14)	-0.04783	-5.41
sy1/2ch1/2	-0.07230	-0.59	AR1,1(lag1)	3.02676	25.97
sy1/2sh1/2	-0.27325	-2.25	AR1,2(lag2)	-3.51019	-11.19
			AR1,3(lag3)	1.83391	6.20
			AR1,4(lag4)	-0.35733	-3.66
			AR2,1(lag17)	-0.01906	-2.62
			AR2,2(lag21)	0.0041434	0.54
			AR2,3(lag22)	0.04283	5.25
			AR2,4(lag23)	0.09431	11.20
			AR2,5(lag24)	0.12547	14.87
			AR2,6(lag25)	0.06023	7.49
			AR2,7(lag26)	0.04514	6.01
			AR2,8(lag48)	0.04245	6.59
	Adj R-Sq 0.7769			*Pseudo* R-Sq	

Table A.4: Parameter estimates for Area 4 temperature OLS model and ARIMA model

Variables	OLS model for area 4 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	45.85318	795.13	MU	0.01815	0.04
cy	-23.00371	-282.09	MA1,1(lag1)	0.55473	7.46
sy	-9.35044	-114.64	MA1,2(lag2)	0.91470	14.39
cy1/2	-0.37940	-4.65	MA1,3(lag3)	-0.58590	-11.48
sy1/2	-1.28776	-15.79	MA1,4(lag4)	-0.07643	-5.94
ch	-4.17609	-51.21	MA1,5(lag5)	-0.06371	-5.82
sh	-6.45539	-79.16	MA1,6(lag6)	0.0048398	0.51
ch1/2	0.28886	3.54	MA1,7(lag7)	-0.0009381	-0.12
sh1/2	1.74559	21.40	MA1,8(lag8)	-0.0000851	-0.01
cych	2.09257	18.14	AR1,1(lag1)	1.72339	23.27
cysh	1.57209	13.63	AR1,2(lag2)	0.13362	1.16
sych	0.18651	1.62	AR1,3(lag3)	-1.65638	-14.61
sysh	-0.96400	-8.36	AR1,4(lag4)	0.78884	13.19
cy1/2ch1/2	0.05737	0.50	AR2,1(lag18)	0.01845	2.47
cy1/2sh1/2	0.39693	3.44	AR2,2(lag19)	0.0086871	1.13
sy1/2ch1/2	0.02616	0.23	AR2,3(lag20)	-0.0000129	-0.00
sy1/2sh1/2	-0.43083	-3.74	AR2,4(lag21)	-0.0007346	-0.09
			AR2,5(lag22)	0.01806	2.24
			AR2,6(lag23)	0.06994	8.80
			AR2,7(lag24)	0.12781	16.51
			AR2,8(lag25)	0.04778	6.42
			AR2,9(lag48)	0.05425	8.64
	Adj R-Sq 0.7965			*Pseudo* R-Sq	

Table A.5: Parameter estimates for Area 5 temperature OLS model and ARIMA model

Variables	OLS model for area 5 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	41.76664	668.75	MU	0.84555	1.71
cy	-23.56502	-266.82	MA1,1(lag1)	0.41298	11.26
sy	-9.27887	-105.04	MA1,2(lag2)	0.78321	17.51
cy1/2	-0.47427	-5.37	MA1,3(lag3)	-0.59038	-24.31
sy1/2	-1.57139	-17.79	MA1,4(lag4)	-0.10454	-9.84
ch	-5.00326	-56.65	MA1,5(lag5)	-0.06580	-6.46
sh	-6.64150	-75.20	MA1,6(lag6)	-0.03145	-3.24
ch1/2	0.64961	7.35	MA1,7(lag7)	-0.03053	-3.16
sh1/2	1.48209	16.78	MA1,8(lag8)	0.0095628	1.01
cych	2.56801	20.56	MA1,9(lag9)	0.0032589	0.35
cysh	1.67619	13.42	MA1,10(lag10)	-0.0027625	-0.29
sych	0.45248	3.62	MA1,11(lag11)	0.01837	1.98
sysh	-0.44084	-3.53	MA1,12(lag12)	0.03366	3.90
cy1/2ch1/2	0.02745	0.22	MA1,13(lag13)	-0.0046874	-0.57
cy1/2sh1/2	0.81138	6.50	MA1,14(lag14)	-0.01855	-2.25
sy1/2ch1/2	-0.07055	-0.56	AR1,1(lag1)	1.62996	45.08
sy1/2sh1/2	-0.38333	-3.07	AR1,2(lag2)	0.10308	1.26
			AR1,3(lag3)	-1.54787	-20.27
			AR1,4(lag4)	0.78790	27.18
			AR2,1(lag22)	0.02767	4.15
			AR2,2(lag23)	0.08400	12.60
			AR2,3(lag24)	0.14594	21.92
			AR2,4(lag25)	0.08361	12.70
			AR2,5(lag26)	0.02341	3.61
			AR2,6(lag48)	0.06437	10.07
	Adj R-Sq 0.7785			*Pseudo* R-Sq	

Table A.6: Parameter estimates for Area 6 temperature OLS model and ARIMA model

Variables	OLS model for area 6 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	41.79153	774.18	MU	0.79326	1.87
cy	-24.07018	-315.33	MA1,1(lag1)	0.95389	9.75
sy	-9.50387	-124.48	MA1,2(lag2)	0.46228	2.85
cy1/2	-0.85695	-11.23	MA1,3(lag3)	-0.45435	-5.93
sy1/2	-0.89293	-11.70	MA1,4(lag4)	-0.01101	-1.01
ch	-2.90461	-38.05	MA1,5(lag5)	-0.01806	-1.65
sh	-4.07305	-53.35	MA1,6(lag6)	-0.01379	-1.43
ch1/2	0.50211	6.58	MA1,7(lag7)	-0.01214	-1.24
sh1/2	0.98397	12.89	MA1,8(lag8)	-0.0028838	-0.31
cych	1.73261	16.05	MA1,9(lag9)	0.0008195	0.09
cysh	1.45416	13.47	MA1,10(lag10)	-0.0066502	-0.70
sych	0.05914	0.55	MA1,11(lag11)	0.02607	2.69
sysh	-0.57801	-5.35	MA1,12(lag12)	-0.04014	-5.73
cy1/2ch1/2	-0.05720	-0.53	AR1,1(lag1)	2.09387	21.41
cy1/2sh1/2	0.27326	2.53	AR1,2(lag2)	-0.66522	-2.46
sy1/2ch1/2	-0.05625	-0.52	AR1,3(lag3)	-1.02925	-3.92
sy1/2sh1/2	0.08230	0.76	AR1,4(lag4)	0.59784	6.64
			AR2,1(lag12)	-0.02738	-3.53
			AR2,2(lag22)	0.01310	1.98
			AR2,3(lag23)	0.04206	6.38
			AR2,4(lag24)	0.06704	10.16
			AR2,5(lag25)	0.03681	5.60
			AR2,6(lag48)	0.04471	7.04
	Adj R-Sq 0.8204			*Pseudo* R-Sq	

Table A.7: Parameter estimates for Area 7 temperature OLS model and ARIMA model

Variables	OLS model for area 7 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	41.17814	702.12	MU	0.29392	0.66
cy	-24.36378	-293.78	MA1,1(lag1)	0.41665	13.96
sy	-9.69224	-116.85	MA1,2(lag2)	0.69876	23.68
cy1/2	-1.19113	-14.36	MA1,3(lag3)	-0.66945	-26.72
sy1/2	-1.67236	-20.16	MA1,4(lag4)	-0.02766	-2.43
ch	-3.53302	-42.60	MA1,5(lag5)	-0.07692	-7.23
sh	-5.75359	-69.37	MA1,6(lag6)	-0.03304	-3.34
ch1/2	0.43589	5.26	MA1,7(lag7)	-0.03987	-4.10
sh1/2	0.90348	10.89	MA1,8(lag8)	-0.03663	-4.33
cych	1.97683	16.85	MA1,9(lag9)	0.01940	2.36
cysh	1.79847	15.33	MA1,10(lag10)	0.01131	1.33
sych	0.43342	3.69	AR1,1(lag1)	1.55323	53.03
sysh	-0.66213	-5.64	AR1,2(lag2)	0.18315	4.25
cy1/2ch1/2	-0.03517	-0.30	AR1,3(lag3)	-1.53364	-39.08
cy1/2sh1/2	0.56272	4.80	AR1,4(lag4)	0.76809	30.40
sy1/2ch1/2	-0.23025	-1.96	AR2,1(lag15)	0.01832	2.57
sy1/2sh1/2	-0.05231	-0.45	AR2,2(lag16)	0.02109	3.04
			AR2,3(lag22)	0.01960	2.93
			AR2,4(lag23)	0.07282	10.87
			AR2,5(lag24)	0.11778	17.80
			AR2,6(lag25)	0.07828	11.84
			AR2,7(lag48)	0.04658	7.47
	Adj R-Sq 0.8040			*Pseudo* R-Sq	

Table A.8: Parameter estimates for Area 8 temperature OLS model and ARIMA model

Variables	OLS model for area 8 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	50.27232	889.88	MU	0.32442	0.73
cy	-20.46376	-256.16	MA1,1(lag1)	0.76779	5.83
sy	-9.84913	-123.27	MA1,2(lag2)	0.75558	3.64
cy1/2	0.69028	8.64	MA1,3(lag3)	-0.47952	-2.73
sy1/2	-1.01067	-12.65	MA1,4(lag4)	-0.56240	-2.98
ch	-2.73663	-34.25	MA1,5(lag5)	0.27081	3.59
sh	-3.35004	-41.93	MA1,6(lag6)	0.02159	1.76
ch1/2	0.26905	3.37	MA1,7(lag7)	-0.0000452	-0.00
sh1/2	0.69913	8.75	MA1,8(lag8)	-0.0046638	-0.43
cych	1.80916	16.01	MA1,9(lag9)	-0.0022103	-0.21
cysh	1.94477	17.21	MA1,10(lag10)	0.02545	2.37
sych	0.10668	0.94	MA1,11(lag11)	-0.0059098	-0.51
sysh	-0.23780	-2.10	MA1,12(lag12)	-0.0059070	-0.50
cy1/2ch1/2	-0.15091	-1.34	MA1,13(lag13)	-0.01798	-1.59
cy1/2sh1/2	0.30668	2.71	MA1,14(lag14)	-0.03876	-4.06
sy1/2ch1/2	-0.04859	-0.43	AR1,1(lag1)	1.88751	14.33
sy1/2sh1/2	-0.25742	-2.28	AR1,2(lag2)	-0.21074	-0.61
			AR1,3(lag3)	-1.30043	-3.70
			AR1,4(lag4)	0.10700	0.30
			AR1,5(lag5)	0.88914	3.00
			AR1,6(lag6)	-0.38523	-3.99
			AR2,1(lag22)	0.04519	5.95
			AR2,2(lag23)	0.08888	11.58
			AR2,3(lag24)	0.13535	17.05
			AR2,4(lag25)	0.09145	11.82
			AR2,5(lag26)	0.03474	4.67
			AR2,6(lag48)	0.05285	8.24
	Adj R-Sq 0.7629			*Pseudo* R-Sq	

Table A.9: Parameter estimates for Area 9 temperature OLS model and ARIMA model

Variables	OLS model for area 9 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	49.26013	894.19	MU	0.58085	1.31
cy	-21.57163	-276.91	MA1,1(lag1)	0.57922	1.68
sy	-9.43068	-121.04	MA1,2(lag2)	-0.30959	-0.66
cy1/2	0.47826	6.14	MA1,3(lag3)	0.26579	0.58
sy1/2	-1.04624	-13.43	MA1,4(lag4)	0.24472	0.59
ch	-2.34433	-30.09	MA1,5(lag5)	-0.52648	-2.68
sh	-3.99691	-51.30	MA1,6(lag6)	-0.11385	-3.44
ch1/2	0.43771	5.62	MA1,7(lag7)	-0.06716	-4.26
sh1/2	0.74188	9.52	MA1,8(lag8)	-0.02259	-1.46
cych	1.48383	13.47	MA1,9(lag9)	0.01677	1.97
cysh	1.98540	18.02	MA1,10(lag10)	-0.01126	-1.29
sych	0.13363	1.21	AR1,1(lag1)	1.79431	5.19
sysh	-0.12585	-1.14	AR1,2(lag2)	-1.17751	-1.33
cy1/2ch1/2	-0.36134	-3.28	AR1,3(lag3)	0.67948	0.63
cy1/2sh1/2	0.18370	1.67	AR1,4(lag4)	-0.12148	-0.12
sy1/2ch1/2	-0.03766	-0.34	AR1,5(lag5)	-0.75994	-1.01
sy1/2sh1/2	-0.02068	-0.19	AR1,6(lag6)	0.56113	2.11
			AR2,1(lag16)	0.02912	3.92
			AR2,2(lag22)	0.0075080	1.14
			AR2,3(lag23)	0.05916	9.00
			AR2,4(lag24)	0.10311	15.67
			AR2,5(lag25)	0.05218	7.95
	Adj R-Sq 0.7844			*Pseudo* R-Sq	

Table A.10: Parameter estimates for Area 10 temperature OLS model and ARIMA model

Variables	OLS model for area 10 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	49.31444	891.76	MU	0.02587	0.06
cy	-20.96646	-268.12	MA1,1(lag1)	1.21930	2.83
sy	-9.23282	-118.05	MA1,2(lag2)	-0.54477	-0.93
cy1/2	0.32775	4.19	MA1,3(lag3)	-0.05091	-0.16
sy1/2	-0.89208	-11.41	MA1,4(lag4)	-0.05064	-3.75
ch	-2.88941	-36.95	MA1,5(lag5)	-0.02934	-1.02
sh	-3.93681	-50.34	MA1,6(lag6)	-0.0062761	-0.37
ch1/2	0.14975	1.91	MA1,7(lag7)	-0.02292	-2.10
sh1/2	1.14628	14.66	MA1,8(lag8)	0.0040361	0.27
cych	1.54790	14.00	MA1,9(lag9)	-0.0090427	-0.90
cysh	1.90037	17.18	MA1,10(lag10)	0.01878	2.28
sych	0.05776	0.52	AR1,1(lag1)	2.36754	5.50
sysh	-0.61584	-5.57	AR1,2(lag2)	-2.02599	-1.88
cy1/2ch1/2	-0.04508	-0.41	AR1,3(lag3)	0.58903	0.58
cy1/2sh1/2	0.22720	2.05	AR1,4(lag4)	0.05407	0.15
sy1/2ch1/2	-0.11820	-1.07	AR2,1(lag22)	0.05401	7.90
sy1/2sh1/2	-0.17990	-1.63	AR2,2(lag23)	0.08562	12.59
			AR2,3(lag24)	0.12695	19.05
			AR2,4(lag25)	0.07042	10.84
	Adj R-Sq 0.7750			*Pseudo* R-Sq	

Table A.11: Parameter estimates for Area 11 temperature OLS model and ARIMA model

Variables	OLS model for area 11 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	45.78652	734.10	MU	0.03204	0.06
cy	-23.44532	-265.83	MA1,1(lag1)	-0.89742	-9.52
sy	-9.50666	-107.77	MA1,2(lag2)	-0.52341	-5.18
cy1/2	-0.32138	-3.64	MA1,3(lag3)	-0.04892	-0.52
sy1/2	-1.83719	-20.83	MA1,4(lag4)	0.41648	4.21
ch	-3.19010	-36.17	MA1,5(lag5)	0.78921	7.98
sh	-4.73052	-53.63	MA1,6(lag6)	0.13223	3.82
ch1/2	0.50761	5.75	MA1,7(lag7)	0.09400	3.27
sh1/2	0.99196	11.25	MA1,8(lag8)	0.03095	1.34
cych	2.13027	17.08	MA1,9(lag9)	0.0086210	0.41
cysh	1.83806	14.74	MA1,10(lag10)	0.01108	0.55
sych	0.37226	2.98	MA1,11(lag11)	0.03542	1.84
sysh	-0.65427	-5.24	MA1,12(lag12)	0.05899	3.29
cy1/2ch1/2	-0.06176	-0.50	MA1,13(lag13)	0.05419	3.39
cy1/2sh1/2	0.34849	2.79	MA1,14(lag14)	0.01934	1.56
sy1/2ch1/2	-0.11563	-0.93	AR1,1(lag1)	0.20412	2.17
sy1/2sh1/2	-0.14387	-1.15	AR1,2(lag2)	0.42964	4.18
			AR1,3(lag3)	0.42342	3.90
			AR1,4(lag4)	0.38179	4.31
			AR1,5(lag5)	0.26654	2.62
			AR1,6(lag6)	-0.74499	-9.06
			AR2,1(lag15)	0.04271	4.60
			AR2,2(lag16)	0.04984	6.52
			AR2,3(lag17)	0.03929	5.37
			AR2,4(lag18)	0.03055	4.19
			AR2,5(lag19)	0.03349	4.54

			AR2,6(lag20)	0.02862	3.82
			AR2,7(lag21)	0.0083958	1.13
			AR2,8(lag22)	0.03201	4.39
			AR2,9(lag23)	0.06591	9.42
			AR2,10(lag24)	0.09911	14.24
			AR2,11(lag25)	0.06143	8.80
			AR2,12(lag48)	0.06422	9.77
	Adj R-Sq 0.7691			*Pseudo* R-Sq	

Table A.12: Parameter estimates for Area 12 temperature OLS model and ARIMA model

Variables	OLS model for area 12 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	49.21080	849.85	MU	0.03186	0.06
cy	-22.11382	-270.07	MA1,1(lag1)	1.47667	5.63
sy	-9.34121	-114.06	MA1,2(lag2)	-0.75012	-1.91
cy1/2	0.13779	1.68	MA1,3(lag3)	0.01338	0.07
sy1/2	-1.33131	-16.26	MA1,4(lag4)	-0.03528	-1.90
ch	-3.00817	-36.73	MA1,5(lag5)	-0.0069754	-0.40
sh	-4.78603	-58.45	MA1,6(lag6)	-0.01032	-0.81
ch1/2	0.53958	6.59	MA1,7(lag7)	-0.0059109	-0.46
sh1/2	0.99666	12.17	MA1,8(lag8)	-0.0001339	-0.01
cych	1.90030	16.41	MA1,9(lag9)	-0.01553	-1.29
cysh	1.92016	16.58	MA1,10(lag10)	0.02678	3.18
sych	0.38160	3.29	AR1,1(lag1)	2.64402	10.08
sysh	-0.47518	-4.10	AR1,2(lag2)	-2.58944	-3.71
cy1/2ch1/2	-0.18878	-1.63	AR1,3(lag3)	1.00625	1.49
cy1/2sh1/2	0.29330	2.53	AR1,4(lag4)	-0.07034	-0.30
sy1/2ch1/2	-0.11114	-0.96	AR2,1(lag22)	0.02926	4.33
sy1/2sh1/2	-0.21606	-1.87	AR2,2(lag23)	0.07014	10.27
			AR2,3(lag24)	0.10945	15.91
			AR2,4(lag25)	0.06292	9.20
			AR2,5(lag26)	0.01934	2.88
			AR2,6(lag27)	-0.01528	-2.32
			AR2,7(lag48)	0.04991	8.04
	Adj R-Sq 0.7772			*Pseudo* R-Sq	

Table A.13: Parameter estimates for Area 13 temperature OLS model and ARIMA model

Variables	OLS model for area 13 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	47.59976	870.86	MU	0.03531	0.08
cy	-21.97701	-284.34	MA1,1(lag1)	1.74726	4.01
sy	-8.96528	-115.97	MA1,2(lag2)	-1.11623	-1.62
cy1/2	-0.57777	-7.48	MA1,3(lag3)	0.19900	0.57
sy1/2	-0.70742	-9.15	MA1,4(lag4)	-0.02781	-1.60
ch	-3.25425	-42.10	MA1,5(lag5)	-0.0006848	-0.04
sh	-5.46367	-70.68	MA1,6(lag6)	-0.02556	-1.73
ch1/2	0.48536	6.28	MA1,7(lag7)	0.0077756	0.40
sh1/2	1.14440	14.81	MA1,8(lag8)	-0.0088365	-0.62
cych	1.67126	15.29	MA1,9(lag9)	0.01042	0.65
cysh	1.55830	14.26	MA1,10(lag10)	0.01078	0.73
sych	0.45336	4.15	AR1,1(lag1)	2.84495	6.52
sysh	-0.32833	-3.00	AR1,2(lag2)	-3.04811	-2.62
cy1/2ch1/2	-0.20794	-1.90	AR1,3(lag3)	1.38727	1.25
cy1/2sh1/2	0.53362	4.88	AR1,4(lag4)	-0.19138	-0.51
sy1/2ch1/2	-0.06674	-0.61	AR2,1(lag22)	0.01451	2.20
sy1/2sh1/2	-0.09694	-0.89	AR2,2(lag23)	0.10457	15.84
			AR2,3(lag24)	0.12773	19.37
			AR2,4(lag25)	0.10044	15.25
	Adj R-Sq 0.7949			*Pseudo* R-Sq	

Table A.14: Parameter estimates for Area 14 temperature OLS model and ARIMA model

Variables	OLS model for area 14 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	49.43782	904.02	MU	0.03308	0.08
cy	-22.68800	-293.39	MA1,1(lag1)	0.93801	1.85
sy	-8.51934	-110.15	MA1,2(lag2)	0.12974	0.16
cy1/2	-0.34135	-4.41	MA1,3(lag3)	-0.42664	-1.06
sy1/2	-1.17021	-15.13	MA1,4(lag4)	-0.01995	-1.70
ch	-2.67421	-34.58	MA1,5(lag5)	-0.03108	-1.65
sh	-5.47424	-70.78	MA1,6(lag6)	-0.02134	-1.60
ch1/2	0.32968	4.26	MA1,7(lag7)	-0.02163	-2.14
sh1/2	1.14416	14.79	MA1,8(lag8)	0.0064362	0.70
cych	1.40235	12.82	AR1,1(lag1)	2.02872	4.01
cysh	1.69564	15.51	AR1,2(lag2)	-0.91245	-0.68
sych	0.37170	3.40	AR1,3(lag3)	-0.60527	-0.47
sysh	-0.46308	-4.23	AR1,4(lag4)	0.47476	1.09
cy1/2ch1/2	-0.08886	-0.81	AR2,1(lag22)	0.02346	3.57
cy1/2sh1/2	0.34404	3.15	AR2,2(lag23)	0.07607	11.55
sy1/2ch1/2	-0.10780	-0.99	AR2,3(lag24)	0.09089	13.88
sy1/2sh1/2	-0.17774	-1.62	AR2,4(lag25)	0.06100	9.43
	Adj R-Sq 0.8002			*Pseudo* R-Sq	

Table A.15: Parameter estimates for Area 16 temperature OLS model and ARIMA model

Variables	OLS model for area 16 temperature		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	51.54316	1016.08	MU	0.01681	0.05
cy	-18.58680	-259.11	MA1,1(lag1)	2.02147	9.72
sy	-9.94520	-138.62	MA1,2(lag2)	-1.36817	-4.32
cy1/2	0.38316	5.34	MA1,3(lag3)	0.15570	1.37
sy1/2	0.09961	1.39	MA1,4(lag4)	0.08743	2.45
ch	-4.44462	-61.95	MA1,5(lag5)	-0.02202	-1.35
sh	-4.09325	-57.06	MA1,6(lag6)	0.0036554	0.22
ch1/2	1.05080	14.65	MA1,7(lag7)	0.01197	0.73
sh1/2	0.72366	10.09	MA1,8(lag8)	0.0092201	0.85
cych	1.22645	12.09	AR1,1(lag1)	3.19673	15.37
cysh	0.04467	0.44	AR1,2(lag2)	-3.97479	-7.09
sych	0.37146	3.66	AR1,3(lag3)	2.24953	4.22
sysh	0.07618	0.75	AR1,4(lag4)	-0.47666	-2.68
cy1/2ch1/2	0.10744	1.06	AR2,1(lag22)	-0.0097443	-1.49
cy1/2sh1/2	0.82870	8.17	AR2,2(lag23)	0.06356	9.73
sy1/2ch1/2	-0.30109	-2.97	AR2,3(lag24)	0.14923	22.88
sy1/2sh1/2	-0.08427	-0.83	AR2,4(lag25)	0.06438	9.88
	Adj R-Sq 0.7814			*Pseudo* R-Sq	

Table B.1 to B.15: Estimated OLS and ARMA Models for Wind Speed

Table B.1: Parameter estimates for Area 1 wind speed OLS model and ARIMA model

Variables	OLS model for area 1 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.96461	336.60	MU	0.0005316	0.10
cy	0.09646	31.45	MA1,1(lag1)	-0.14446	-17.63
sy	0.03434	17.75	MA1,2(lag2)	0.07022	8.30
cy1/2	0.00782	4.60	MA1,3(lag3)	0.01746	2.20
sy1/2	0.00064806	0.38	MA1,4(lag4)	0.04721	6.20
ch	0.02012	11.70	MA1,5(lag5)	0.02790	3.80
sh	0.04925	27.41	MA1,6(lag6)	-0.01244	-1.82
ch1/2	-0.00276	-1.68	AR1,1(lag1)	0.89986	165.46
sh1/2	0.00536	3.24	AR2,1(lag24)	0.04653	7.51
CDD	-0.00290	-8.24			
HDD	-0.00220	-16.73			
	Adj R-Sq 0.0980			*Pseudo* R-Sq 0.8359	

Table B.2: Parameter estimates for Area 2 wind speed OLS model and ARIMA model

Variables	OLS model for area 2 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.87174	295.31	MU	0.00002032	0.00
cy	0.07575	24.74	MA1,1(lag1)	-0.03719	-4.42
sy	0.02640	12.86	MA1,2(lag2)	0.03572	4.41
cy1/2	-0.00163	-0.97	MA1,3(lag3)	-0.0013902	-0.18
sy1/2	-0.00337	-1.97	MA1,4(lag4)	0.0069704	0.95
ch	0.03081	18.17	MA1,5(lag5)	-0.0050558	-0.72
sh	0.04583	26.63	AR1,1(lag1)	0.87740	152.50
ch1/2	0.00785	4.83	AR2,1(lag24)	0.01688	2.73
sh1/2	-0.00477	-2.93			
CDD	0.00187	5.64			
HDD	-0.00128	-8.62			
	Adj R-Sq 0.0698			*Pseudo* R-Sq 0.7871	

Table B.3: Parameter estimates for Area 3 wind speed OLS model and ARIMA model

Variables	OLS model for area 3 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.97914	313.63	MU	0.0006400	0.12
cy	0.12737	39.65	MA1,1(lag1)	-0.08187	-10.28
sy	0.03741	18.76	MA1,2(lag2)	0.06285	7.87
cy1/2	0.00924	5.34	MA1,3(lag3)	0.01490	1.96
sy1/2	-0.00475	-2.77	MA1,4(lag4)	0.05236	7.11
ch	0.00286	1.66	MA1,5(lag5)	0.02338	3.28
sh	0.05330	29.75	MA1,6(lag6)	0.0020119	0.30
ch1/2	-0.00265	-1.60	AR1,1(lag1)	0.90860	180.11
sh1/2	0.00553	3.31	AR2,1(lag24)	0.04576	7.39
CDD	-0.00067866	-1.73			
HDD	-0.00242	-19.03			
	Adj R-Sq 0.1155			*Pseudo* R-Sq 0.8355	

Table B.4: Parameter estimates for Area 4 wind speed OLS model and ARIMA model

Variables	OLS model for area 4 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.90349	308.55	MU	0.0001687	0.03
cy	0.07208	23.14	MA1,1(lag1)	-0.04642	-5.99
sy	0.01849	9.66	MA1,2(lag2)	0.07049	9.17
cy1/2	0.00494	3.03	MA1,3(lag3)	0.02569	3.51
sy1/2	0.00117	0.72	MA1,4(lag4)	0.04321	6.03
ch	0.00797	4.81	MA1,5(lag5)	0.02362	3.45
sh	0.05138	29.32	AR1,1(lag1)	0.90859	195.84
ch1/2	0.00521	3.33	AR2,1(lag24)	0.04081	6.59
sh1/2	0.00517	3.26			
CDD	-0.00267	-8.31			
HDD	-0.00042273	-3.34			
	Adj R-Sq 0.1168			*Pseudo* R-Sq 0.8213	

Table B.5: Parameter estimates for Area 5 wind speed OLS model and ARIMA model

Variables	OLS model for area 5 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.98138	309.87	MU	-0.0001825	-0.04
cy	0.09650	31.40	MA1,1(lag1)	-0.11447	-15.75
sy	0.02973	15.52	MA1,2(lag2)	0.06317	8.53
cy1/2	0.01329	8.00	MA1,3(lag3)	-0.0080654	-1.17
sy1/2	-0.00505	-3.07	AR1,1(lag1)	0.89422	231.64
ch	0.00626	3.64	AR2,1(lag24)	0.05329	8.63
sh	0.04233	23.79			
ch1/2	0.00592	3.68			
sh1/2	0.00944	5.81			
CDD	-0.00426	-11.13			
HDD	-0.00079394	-6.71			
	Adj R-Sq 0.1375			*Pseudo* R-Sq 0.8213	

Table B.6: Parameter estimates for Area 6 wind speed OLS model and ARIMA model

Variables	OLS model for area 6 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.96605	253.39	MU	-0.0002074	-0.04
cy	0.05495	14.68	MA1,1(lag1)	-0.12173	-16.13
sy	0.00346	1.60	MA1,2(lag2)	0.03545	4.60
cy1/2	0.01182	6.63	MA1,3(lag3)	0.0067011	0.90
sy1/2	0.00071449	0.41	MA1,4(lag4)	0.03389	4.68
ch	-0.01823	-10.27	MA1,5(lag5)	0.02167	3.17
sh	0.06167	34.08	AR1,1(lag1)	0.90956	211.20
ch1/2	0.00272	1.59	AR2,1(lag24)	0.06064	9.81
sh1/2	0.01531	8.89			
CDD	-0.00436	-8.71			
HDD	0.00125	8.52			
	Adj R-Sq 0.1539			*Pseudo* R-Sq 0.8667	

Table B.7: Parameter estimates for Area 7 wind speed OLS model and ARIMA model

Variables	OLS model for area 7 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.94787	314.96	MU	-0.0008194	-0.19
cy	0.08681	29.50	MA1,1(lag1)	-0.05268	-7.09
sy	0.02170	12.31	MA1,2(lag2)	0.04462	6.05
cy1/2	0.00825	5.51	MA1,3(lag3)	0.02149	3.08
sy1/2	-0.00007087	-0.05	AR1,1(lag1)	0.89007	217.53
ch	0.01103	7.42	AR2,1(lag24)	0.03536	5.73
sh	0.05556	35.58			
ch1/2	0.00270	1.89			
sh1/2	-0.00102	-0.71			
CDD	-0.00274	-7.08			
HDD	-0.00166	-14.80			
	Adj R-Sq 0.1022			*Pseudo* R-Sq 0.8134	

Table B.8: Parameter estimates for Area 8 wind speed OLS model and ARIMA model

Variables	OLS model for area 8 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.92830	330.86	MU	0.0005121	0.10
cy	0.17281	56.73	MA1,1(lag1)	-0.03917	-5.36
sy	0.05133	24.91	MA1,2(lag2)	0.04468	6.17
cy1/2	0.00857	4.97	MA1,3(lag3)	0.03810	5.50
sy1/2	-0.01102	-6.33	AR1,1(lag1)	0.89993	234.59
ch	-0.00050984	-0.30	AR2,1(lag24)	0.04812	7.80
sh	0.04881	28.55			
ch1/2	-0.00971	-5.91			
sh1/2	-0.01146	-6.96			
CDD	0.00348	10.30			
HDD	-0.00445	-31.62			
	Adj R-Sq 0.1483			*Pseudo* R-Sq 0.8312	

Table B.9: Parameter estimates for Area 9 wind speed OLS model and ARIMA model

Variables	OLS model for area 9 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.93710	320.92	MU	0.0015245	0.28
cy	0.13989	43.41	MA1,1(lag1)	-0.03929	-5.42
sy	0.03806	18.61	MA1,2(lag2)	0.05715	7.96
cy1/2	0.01427	8.25	MA1,3(lag3)	0.01481	2.12
sy1/2	-0.00686	-3.97	MA1,4(lag4)	0.02518	3.71
ch	0.00070542	0.42	AR1,1(lag1)	0.91392	243.37
sh	0.03889	22.36	AR2,1(lag24)	0.03297	5.33
ch1/2	-0.00482	-2.94			
sh1/2	-0.00684	-4.16			
CDD	0.00007386	0.21			
HDD	-0.00345	-24.19			
	Adj R-Sq 0.1099			*Pseudo* R-Sq 0.8425	

Table B.10: Parameter estimates for Area 10 wind speed OLS model and ARIMA model

Variables	OLS model for area 10 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.95365	318.97	MU	0.0008883	0.17
cy	0.15773	48.78	MA1,1(lag1)	-0.05466	-6.33
sy	0.04686	22.49	MA1,2(lag2)	0.03641	4.28
cy1/2	0.01144	6.49	MA1,3(lag3)	0.01321	1.65
sy1/2	-0.00665	-3.76	MA1,4(lag4)	0.01809	2.36
ch	-0.00424	-2.44	MA1,5(lag5)	0.0091528	1.24
sh	0.04900	27.58	MA1,6(lag6)	0.0067819	0.94
ch1/2	-0.00683	-4.06	MA1,7(lag7)	0.01166	1.66
sh1/2	-0.01222	-7.22	MA1,8(lag8)	-0.01018	-1.50
CDD	0.00125	3.59	AR1,1(lag1)	0.90563	148.69
HDD	-0.00414	-28.16	AR2,1(lag24)	0.02648	4.26
	Adj R-Sq 0.1258			*Pseudo* R-Sq 0.8404	

Table B.11: Parameter estimates for Area 11 wind speed OLS model and ARIMA model

Variables	OLS model for area 11 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.96101	314.29	MU	0.0007232	0.13
cy	0.14714	45.03	MA1,1(lag1)	-0.07228	-9.43
sy	0.04119	20.03	MA1,2(lag2)	0.06631	8.67
cy1/2	0.01436	8.00	MA1,3(lag3)	0.01875	2.57
sy1/2	-0.00395	-2.21	MA1,4(lag4)	0.02584	3.62
ch	0.02010	11.31	MA1,5(lag5)	0.0061454	0.90
sh	0.05079	27.90	AR1,1(lag1)	0.90579	199.81
ch1/2	-0.00584	-3.40	AR2,1(lag24)	0.04539	7.35
sh1/2	-0.00325	-1.89			
CDD	0.00060016	1.59			
HDD	-0.00445	-34.54			
	Adj R-Sq 0.0932			*Pseudo* R-Sq 0.8315	

Table B.12: Parameter estimates for Area 12 wind speed OLS model and ARIMA model

Variables	OLS model for area 12 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.93575	322.66	MU	0.0006392	0.13
cy	0.15792	49.01	MA1,1(lag1)	-0.04777	-6.20
sy	0.04358	21.33	MA1,2(lag2)	0.04875	6.46
cy1/2	0.00993	5.65	MA1,3(lag3)	0.0034000	0.47
sy1/2	0.00221	1.26	MA1,4(lag4)	0.02228	3.20
ch	0.00471	2.72	AR1,1(lag1)	0.89207	195.28
sh	0.04382	24.45	AR2,1(lag24)	0.04547	7.37
ch1/2	-0.00445	-2.66			
sh1/2	-0.00805	-4.79			
CDD	0.00066948	2.09			
HDD	-0.00417	-29.97			
	Adj R-Sq 0.1160			*Pseudo* R-Sq 0.8168	

Table B.13: Parameter estimates for Area 13 wind speed OLS model and ARIMA model

Variables	OLS model for area 13 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.96708	331.85	MU	0.0008905	0.18
cy	0.09244	29.43	MA1,1(lag1)	-0.06305	-7.33
sy	0.01502	7.81	MA1,2(lag2)	0.06224	7.35
cy1/2	0.00800	4.88	MA1,3(lag3)	0.0058433	0.74
sy1/2	-0.01416	-8.72	MA1,4(lag4)	0.01328	1.76
ch	0.00131	0.80	MA1,5(lag5)	0.0058816	0.81
sh	0.04567	26.56	MA1,6(lag6)	0.0069419	0.97
ch1/2	-0.00642	-4.10	MA1,7(lag7)	-0.0073438	-1.07
sh1/2	-0.00103	-0.65	AR1,1(lag1)	0.89755	148.95
CDD	-0.00245	-7.22	AR2,1(lag24)	0.05793	9.36
HDD	-0.00128	-9.42			
	Adj R-Sq 0.1138			*Pseudo* R-Sq 0.8268	

Table B.14: Parameter estimates for Area 14 wind speed OLS model and ARIMA model

Variables	OLS model for area 14 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.92920	308.85	MU	0.0004023	0.07
cy	0.09603	27.61	MA1,1(lag1)	-0.01621	-2.22
sy	0.02863	14.01	MA1,2(lag2)	0.07566	10.48
cy1/2	0.01137	6.29	MA1,3(lag3)	0.02277	3.30
sy1/2	-0.00032292	-0.18	AR1,1(lag1)	0.90064	233.60
ch	0.01537	8.80	AR2,1(lag24)	0.05324	8.62
sh	0.05261	28.08			
ch1/2	-0.00437	-2.58			
sh1/2	-0.00377	-2.21			
CDD	-0.00078290	-2.29			
HDD	-0.00200	-13.56			
	Adj R-Sq 0.0828			*Pseudo* R-Sq 0.8062	

Table B.15: Parameter estimates for Area 16 wind speed OLS model and ARIMA model

Variables	OLS model for area 16 wind speed		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	0.87544	335.31	MU	0.0001804	0.04
cy	0.07942	27.00	MA1,1(lag1)	-0.05133	-6.62
sy	0.03625	17.63	MA1,2(lag2)	0.06788	8.93
cy1/2	0.00482	2.98	MA1,3(lag3)	0.0069688	0.96
sy1/2	0.00039353	0.23	MA1,4(lag4)	0.03122	4.47
ch	0.03358	19.81	AR1,1(lag1)	0.89355	193.72
sh	0.04920	29.64	AR2,1(lag24)	0.03911	6.33
ch1/2	0.00482	3.07			
sh1/2	-0.00409	-2.62			
CDD	-0.00098955	-2.76			
HDD	-0.00206	-14.30			
	Adj R-Sq 0.0902			*Pseudo* R-Sq 0.8054	

Table C.1 to C.6: Estimated OLS and ARMA models for Load

Table C.1: Parameter estimates for NE1 load OLS model and ARIMA model

Variables	OLS model for NE1 load		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	3.48451	3396.83	MU	-0.0000433	-0.04
t	1.885305E-7	8.91	MA1,1(lag1)	-0.18034	-19.08
cy	-0.00021795	-0.57	MA1,2(lag2)	0.06932	6.73
sy	-0.01111	-44.07	MA1,3(lag3)	0.17114	17.93
cy1/2	0.02647	53.40	MA1,4(lag4)	0.10313	12.28
sy1/2	0.01708	73.11	MA1,5(lag5)	0.07058	9.04
cw	0.01982	73.23	MA1,6(lag6)	0.05285	7.05
sw	-0.00903	-39.70	MA1,7(lag7)	0.01835	2.53
cw1/2	-0.00925	-40.78	MA1,8(lag8)	0.03290	4.85
sw1/2	0.00614	26.57	AR1,1(lag1)	0.92635	129.19
cw1/4	-0.00226	-10.54	AR2,1(lag24)	0.46589	76.39
sw1/4	-0.00264	-12.22	AR3,1(lag48)	0.04265	6.36
ch1/2	0.00262	4.33			
sh1/2	-0.04063	-78.94			
ch1/4	-0.00347	-14.40			
Sh1/4	0.00400	17.81			
ch	-0.04250	-64.11			
sh	-0.06858	-103.97			
wc	0.00264	7.25			
CDD	0.00322	21.68			
newHDD	0.00133	29.42			
CDD^2	0.00002675	3.16			
newHDD^2	0.00000123	1.44			
cych	-0.00068077	-1.97			
sysh	0.00454	14.73			
cysh	-0.00212	-5.94			
sych	-0.00036609	-1.19			
*winter*w72	0.00963	11.76			
*winter*w73	0.01435	16.57			
*winter*w74	0.01967	23.84			
*winter*w75	0.00807	9.68			
*winter*w76	0.00715	8.58			
*summer*w72	0.00346	4.23			
*summer*w73	0.01279	14.74			
*summer*w74	0.00684	8.18			
*summer*w75	0.00778	9.15			
*summer*w76	0.00593	7.09			
	Adj R-Sq 0.9079			*Pseudo* R-Sq 0. 9865	

Table C.2: Parameter estimates for NE2 load OLS model and ARIMA model

Variables	OLS model for NE2 load		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	3.88803	3104.62	MU	-0.0004648	-0.37
t	4.712879E-8	1.80	MA1,1(lag1)	-0.21329	-24.00
cy	-0.00237	-5.36	MA1,2(lag2)	0.01360	1.38
sy	-0.01172	-38.35	MA1,3(lag3)	0.12208	12.84
cy1/2	0.02810	45.54	MA1,4(lag4)	0.10148	11.69
sy1/2	0.02405	81.79	MA1,5(lag5)	0.08268	10.18
cw	0.02563	76.29	MA1,6(lag6)	0.06894	8.91
sw	-0.00836	-29.58	MA1,7(lag7)	0.04443	6.04
cw1/2	-0.01187	-42.16	MA1,8(lag8)	0.04656	6.88
sw1/2	0.00569	19.84	AR1,1(lag1)	0.93095	146.01
cw1/4	-0.00242	-9.09	AR2,1(lag24)	0.40330	65.04
sw1/4	-0.00223	-8.31	AR3,1(lag48)	0.07353	11.14
ch1/2	0.00754	10.04			
sh1/2	-0.03899	-60.97			
ch1/4	-0.00365	-12.21			
Sh1/4	0.00268	9.63			
ch	-0.03011	-36.89			
sh	-0.07044	-85.84			
wc	0.00307	6.79			
CDD	0.00554	35.59			
newHDD	0.00228	32.81			
CDD^2	0.00004684	5.45			
newHDD^2	-0.00000550	-3.10			
cych	-0.00459	-10.75			
sysh	0.00572	15.02			
cysh	-0.00351	-7.85			
sych	-0.00188	-4.95			
*winter*w72	0.00822	8.08			
*winter*w73	0.01464	13.62			
*winter*w74	0.02362	23.10			
*winter*w75	0.01099	10.65			
*winter*w76	0.00663	6.42			
*summer*w72	0.00168	1.66			
*summer*w73	0.01409	13.09			
*summer*w74	0.00890	8.64			
*summer*w75	0.00864	8.21			
*summer*w76	0.00792	7.64			
	Adj R-Sq 0.8870			*Pseudo* R-Sq 0.9862	

Table C.3: Parameter estimates for Boston load OLS model and ARIMA model

Variables	OLS model for Boston load		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	3.41417	3036.04	MU	-0.0000951	-0.11
t	4.538274E-7	19.06	MA1,1(lag1)	-0.22778	-15.95
cy	0.00319	8.25	MA1,2(lag2)	-0.08819	-5.68
sy	-0.00635	-22.69	MA1,3(lag3)	0.0016658	0.11
cy1/2	0.02115	37.69	MA1,4(lag4)	0.01020	0.77
sy1/2	0.01699	61.39	MA1,5(lag5)	0.01913	1.63
cw	0.02436	79.90	MA1,6(lag6)	0.02511	2.41
sw	-0.00874	-34.10	MA1,7(lag7)	0.03995	4.39
cw1/2	-0.01049	-41.02	MA1,8(lag8)	0.05142	6.79
sw1/2	0.00711	27.29	AR1,1(lag1)	0.86176	67.58
cw1/4	-0.00221	-9.16	AR2,1(lag24)	0.35974	58.34
sw1/4	-0.00279	-11.44	AR3,1(lag48)	0.07235	11.07
ch1/2	0.00331	4.86			
sh1/2	-0.03071	-53.13			
ch1/4	-0.00278	-10.27			
Sh1/4	0.00140	5.53			
ch	-0.02939	-39.92			
sh	-0.06412	-87.97			
wc	0.00272	6.62			
CDD	0.00814	63.35			
newHDD	0.00274	36.85			
CDD^2	-0.00007329	-11.02			
$newHDD^2$	-0.00000148	-0.67			
cych	-0.00574	-14.96			
sysh	0.00212	6.14			
cysh	-0.00582	-14.81			
sych	-0.00325	-9.41			
*winter*w72	0.00556	6.03			
*winter*w73	0.01145	11.74			
*winter*w74	0.02092	22.56			
*winter*w75	0.01139	12.19			
*winter*w76	0.00662	7.06			
*summer*w72	-0.00406	-4.41			
*summer*w73	0.00856	8.77			
*summer*w74	0.00625	6.70			
*summer*w75	0.00301	3.20			
*summer*w76	0.00325	3.47			
	Adj R-Sq 0.8930			*Pseudo* R-Sq 0.9856	

Table C.4: Parameter estimates for NY1 load OLS model and ARIMA model

Variables	OLS model for NY1 load		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	3.77153	4096.14	MU	-0.0009575	-0.99
t	5.05178E-7	25.84	MA1,1(lag1)	-0.42422	-40.84
cy	0.01382	41.33	MA1,2(lag2)	-0.09388	-7.44
sy	-0.00100	-4.28	MA1,3(lag3)	0.03457	2.89
cy1/2	0.01422	30.81	MA1,4(lag4)	0.02034	1.92
sy1/2	0.01243	54.95	MA1,5(lag5)	-0.01064	-1.10
cw	0.02266	90.88	MA1,6(lag6)	-0.01152	-1.31
sw	-0.00927	-44.15	MA1,7(lag7)	-0.01256	-1.75
cw1/2	-0.01044	-49.95	AR1,1(lag1)	0.85449	101.72
sw1/2	0.00672	31.56	AR2,1(lag24)	0.52420	90.75
cw1/4	-0.00276	-13.94	AR3,1(lag48)	0.04373	6.49
sw1/4	-0.00250	-12.57			
ch1/2	0.00421	7.55			
sh1/2	-0.02477	-52.42			
ch1/4	-0.00249	-11.20			
Sh1/4	0.00196	9.49			
ch	-0.02381	-39.69			
sh	-0.04838	-80.52			
wc	0.00267	7.94			
CDD	0.00441	41.13			
newHDD	0.00239	39.30			
CDD^2	0.00003512	6.02			
$newHDD^2$	-0.00001771	-9.48			
cych	-0.00097206	-3.14			
sysh	0.00382	13.51			
cysh	-0.00436	-13.47			
sych	-0.00050952	-1.82			
*winter*w72	0.00539	7.14			
*winter*w73	0.00872	10.93			
*winter*w74	0.01530	20.20			
*winter*w75	0.00530	6.95			
*winter*w76	0.00169	2.20			
*summer*w72	0.00006311	0.08			
*summer*w73	0.00967	12.11			
*summer*w74	0.00228	2.97			
*summer*w75	-0.00216	-2.78			
*summer*w76	0.00198	2.57			
	Adj R-Sq 0.8764			*Pseudo* R-Sq 0.9883	

Table C.5: Parameter estimates for NY2 load OLS model and ARIMA model

Variables	OLS model for NY2 load		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	3.48606	3023.02	MU	-0.0002163	-0.21
t	4.221756E-7	17.34	MA1,1(lag1)	-0.22401	-24.63
cy	-0.00170	-3.96	MA1,2(lag2)	0.16865	16.59
sy	-0.01520	-53.46	MA1,3(lag3)	0.13391	14.68
cy1/2	0.02670	46.09	MA1,4(lag4)	0.10321	12.38
sy1/2	0.02045	72.92	MA1,5(lag5)	0.07347	9.35
cw	0.01893	60.84	MA1,6(lag6)	0.07929	10.50
sw	-0.00615	-23.49	MA1,7(lag7)	0.05392	7.95
cw1/2	-0.00841	-32.23	AR1,1(lag1)	0.93061	140.20
sw1/2	0.00488	18.37	AR2,1(lag24)	0.33397	53.41
cw1/4	-0.00140	-5.68	AR3,1(lag48)	0.11221	17.34
sw1/4	-0.00195	-7.85			
ch1/2	0.00676	9.70			
sh1/2	-0.03616	-61.17			
ch1/4	-0.00250	-9.04			
Sh1/4	0.00168	6.50			
ch	-0.02026	-27.01			
sh	-0.06879	-90.15			
wc	0.00222	5.29			
CDD	0.00704	54.21			
newHDD	0.00253	36.76			
CDD^2	0.00002536	3.87			
newHDD^2	-0.00000865	-4.78			
cych	-0.00541	-13.91			
sysh	0.00347	9.84			
cysh	-0.00707	-16.89			
sych	-0.00200	-5.72			
*winter*w72	0.00955	10.11			
*winter*w73	0.01462	14.65			
*winter*w74	0.02440	25.78			
*winter*w75	0.01147	12.02			
*winter*w76	0.00523	5.47			
*summer*w72	0.00055730	0.59			
*summer*w73	0.01327	13.32			
*summer*w74	0.00817	8.58			
*summer*w75	0.00406	4.16			
*summer*w76	0.00611	6.37			
	Adj R-Sq 0.8997			*Pseudo* R-Sq 0. 9843	

Table C.6: Parameter estimates for Long Island load OLS model and ARIMA model

Variables	OLS model for Long Island load		Variable	ARIMA model for Residual	
	Parameter Estimate	t Value		Parameter Estimates	t Value
Intercept	3.32347	1552.08	MU	0.0015425	1.15
t	0.00000401	16.56	MA1,1(lag1)	-0.50028	-14.25
cy	-0.02489	-37.18	MA1,2(lag2)	-0.25890	-6.47
sy	-0.00515	-6.42	MA1,3(lag3)	-0.15221	-4.37
cy1/2	0.04237	43.66	MA1,4(lag4)	-0.12913	-4.62
sy1/2	0.03055	49.87	MA1,5(lag5)	-0.06057	-2.73
cw	-0.01839	-33.55	MA1,6(lag6)	-0.04373	-2.97
sw	-0.00306	-7.25	AR1,1(lag1)	0.65155	19.29
cw1/2	-0.00895	-18.93	AR2,1(lag24)	0.45039	43.16
sw1/2	-0.00415	-9.94	AR3,1(lag48)	0.08755	7.56
cw1/4	0.00259	6.17			
sw1/4	-0.00168	-4.02			
ch1/2	0.00908	7.68			
sh1/2	-0.03401	-34.05			
ch1/4	-0.00073257	-1.56			
Sh1/4	0.00080643	1.84			
ch	-0.00989	-7.62			
sh	-0.09753	-77.41			
wc	0.00379	5.32			
CDD	0.00823	36.48			
newHDD	0.00269	15.03			
CDD^2	0.00001945	1.93			
$newHDD^2$	-0.00003760	-4.51			
cych	-0.00907	-13.28			
sysh	0.00513	8.57			
cysh	-0.00187	-2.73			
sych	-0.00611	-10.16			
*winter*w72	0.02282	14.33			
*winter*w73	0.02456	14.55			
*winter*w74	0.03337	20.75			
*winter*w75	0.01919	11.87			
*winter*w76	0.00766	4.73			
*summer*w72	-0.00053132	-0.33			
*summer*w73	0.02070	12.20			
*summer*w74	0.01155	7.09			
*summer*w75	-0.00126	-0.77			
*summer*w76	0.00317	1.95			
	Adj R-Sq 0.9317			*Pseudo* R-Sq 0.9904	